Body composition changes in the first year postpartum among breastfeeding women living in Palmerston North, New Zealand.
Mother and Infant Nutrition Investigation (MINI) Study

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Abstract

Background: Postpartum weight retention (PPWR) is the retention of weight gained during pregnancy, carried into the postpartum period. The consequences of PPWR for both subsequent pregnancies and long-term health have been studied in detail and can include overweight and obesity and their associated comorbidities. PPWR is affected by several factors, however, the influence of infant feeding mode is subject to conflicting results. Postpartum women in New Zealand have not been studied for their postpartum weight change patterns or the influence of infant feeding status.

Aim: To explore maternal body composition changes at 3-, 6-, and 12-months postpartum in conjunction with infant feeding mode, and to validate bioelectrical impedance analysis (BIA) in assessing body composition in this population.

Method: This was a secondary analysis based on the data collected from the Mother and Infant Nutrition Investigation Study, an observational longitudinal cohort study, from Palmerston North, New Zealand. Breastfeeding women had body composition assessment measures taken at 3-, 6-, and 12-months postpartum (MPP). Total body weight (TW), fat mass (FM), fat free mass (FFM), and body fat percentage (BF%) measures were collected via BIA and BOD POD (air displacement plethysmography). Participants' demographic information and infant feeding mode were collected via a maternal questionnaire. Infant feeding mode at 3MPP (EBF - exclusive breastfeeding or MF - mixed feeding) was used to assess its impact on body composition changes. Statistical analyses were performed using IBM SPSS Statistics, carrying out descriptive statistics, repeated measures ANOVA, Pearson's rank correlation, and cross-classification agreement.

Results: 87 participants with mean (± Standard Deviation (SD)) age 31.5 ± 4.2 years, were recruited. The mean prepregnancy BMI tended to be higher for the MF group (26.2kg/m2), compared to the EBF group (23.8kg/m2), though the difference was not significant. Mean (geometric, 95% CI) prepregnancy weight was significantly lower at 66.8 (64.0, 69.8) kg than the mean (geometric, 95% CI) total weight at 12MPP (68.9 (65.3, 72.8) kg) ($p = 0.046$), resulting in a mean (geometric, 95% CI) weight retention of 3.14 (2.1, 4.7) kg. All participants showed significant changes at 3MPP, 6MPP, and 12MPP for all measures of body composition. TW, FM, and BF% showed a significant reduction over time points ($p < 0.001$), while FFM

showed a significant increase at 6MPP ($p < 0.001$). At 3MPP 83% of participants were EBF. There were significant differences between infant feeding groups for FM, TW, BF%, but not for FFM. However, when combining time and infant feeding mode, there was no statistical significance. Body composition measurements via BIA and BOD POD were strongly associated ($p < 0.001$), and were classified into the same tertiles, with k-statistic agreement levels between 0.5 (moderate) to > 0.80 (very good).

Conclusion: Total body weight, fat mass, and body fat percentage reduced in the postpartum period, irrespective of infant feeding mode at 3MPP. No significant difference was observed between infant feeding groups. However, on average, women had gained weight at 12MPP when compared to prepregnancy weight. Additionally, BIA showed high correlations across all measures of body composition when compared to BODPOD, further supporting the use of BIA in the postpartum population.

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List of Abbreviations

EBF	Exclusive breastfeeding
MF	Mixed feeding
BF	Breastfeeding
FF	Formula feeding
WHO	World Health Organization
MOH	Ministry of Health
MINI	Mother and Infant Nutrition Investigation
3MPP	Three months postpartum
6MPP	Six months postpartum
12MPP	Twelve months postpartum
PPWR	Postpartum weight retention
GWG	Gestational weight gain
BW	Body weight
BMI	Body mass index
TW	Total weight
FM	Fat mass
FFM	Fat free mass
BF%	Body fat percentage
ANOVA	Analysis of variance
SD	Standard deviation
LGA	Large for gestational age
BIA	Bioelectrical impedance analysis
DXA	Dual energy x-ray absorptiometry
ADP	Air displacement plethysmography
TBW	Total body water
ECW	Extracellular water
SF	Skinfold
UWW	Underwater weighing
TBK	Total body potassium
TOBEC	Total body electrical conductivity

Chapter 1: Introduction

1.1 Background

Obesity or being overweight is associated with elevated risk of cardiovascular disease, type 2 diabetes mellitus, hypertension, obstructive sleep apnea, stroke, some types of cancers, and maternal disorders among women of reproductive age (Samnang, An, Jonathan, & Heng, 2023). According to the World Health Organization (WHO), the year 2016 saw more than 1.9 billion adults, 18 years and older, classified as overweight. Of these, over 650 million were obese (WHO, 2021) . Globally, the prevalence of overweight and obesity among women has been subject to a significant upward trend in recent decades. In both low- and middle-income countries, the prevalence of obesity and overweight were higher for women than for men. For all women in 2016, 15% were obese, compared to the 11% for men (WHO, 2021). New Zealand (NZ) follows a similar trajectory. The most recent report for NZ in 2021 showed one in three adults (34%) were classified as obese. For NZ women, the percentage of obesity had risen significantly from 32% to 36% between the years 2020 to 2021 (Ministry of Health, 2021c).

Typically, women are more prone to weight gain and overweight/obesity compared to their male counterparts, especially as they progress from young adults to middle age. It has been estimated that women of reproductive age (18-50 years) gain approximately 700g of weight each year. Additionally, the weight gain for this age group happens at a faster rate than for women aged over 50 years who gain an average of 300g a year (Lucke et al., 2007). As a result, weight management is a significant priority for women's short- and long-term health, especially during their reproductive years. The reproductive life stages, encompassing preconception, pregnancy, and postpartum periods, offer significant influence on weight gain and the development of obesity. Maternal overweight/obesity during both preconception and pregnancy increases the risk of complications, including preeclampsia, gestational diabetes mellitus (GDM), and cesarean delivery (Leddy, Power, & Schulkin, 2008). Following childbirth, it is common for women to retain the excess weight that was gained during pregnancy. This is known as postpartum weight retention (PPWR) and can occur following a single pregnancy or between consecutive pregnancies. The average women will gain around one BMI unit between pregnancies, with greater BMI gains for those with a higher pre-pregnancy BMI (Ku et al., 2023).

The implications of PPWR are substantial, including increased risk to chronic ailments such as cardiovascular disease, osteoarthritis, diabetes, and some cancers. Furthermore, PPWR's influence extends to subsequent pregnancies, whereby entering pregnancy overweight or obese elevates the risk of pregnancy complications, including preeclampsia, gestational diabetes mellitus, caesarean section, stillbirth, congenital anomalies, increased birth weight, and neonates born large for gestational age (Makama, Skouteris, Moran, & Lim, 2021). Beyond the initial year, PPWR exhibits a concerning association with overweight and obesity even after 15 years (Linné, Dye, Barkeling, & Rössner, 2004). Currently, NZ offers minimal specific guidance to support postpartum women with weight management. There is urgent need for postpartum weight management strategies and guidelines to reduce the rates of overweight and obesity in NZ, and contribute to the global effort against the escalating obesity epidemic (Dalrymple, Flynn, Relph, O'Keeffe, & Poston, 2018).

The postpartum period emerges as a critical phase for effective weight management for the prevention of health complications later in life. For many women, returning to their prepregnancy weight at this time proves harder than expected. In a qualitative study investigating nutrition and exercise experiences among postpartum women, participants reported feeling disappointed by not achieving their postpartum weight goals as they thought they should have. Many learned their weight loss goals were unrealistic, while caring for a newborn, validating the difficulties many women face with weight loss at this time (Murray-Davis et al., 2019). On average, PPWR typically observed around the 12-month mark, ranges between 0.5 and 3 kg, however, weight retention can be extremely variable with up to 20% of women retaining more than 4 kg at one year postpartum (Jayasinghe et al., 2022; Makama et al., 2021).

Factors such as prepregnancy weight, gestational weight gain (GWG), infant feeding mode, energy intake, physical activity status, age, parity, ethnicity, income, have been investigated for a relationship to postpartum weight patterns (Somvanshi, 2002). The most consistently reported risk factor of PPWR is GWG more than the Institute of Medicine (IOM) guidelines. GWG is a normal biological response to pregnancy and is calculated as the weight difference between the first prenatal visit and the last visit before delivery. GWG is influenced by the growing fetus, the placenta, amniotic fluids, the uterus, and breast tissue. Blood increases in volume, and additional fat stores are laid, contributing to changes in body composition

(Ministry of Health, 2008; Yaktine & Rasmussen, 2009). NZ follows IOM GWG guidelines. The guidelines for GWG are based on body mass index (BMI, a proxy for body fat based on weight and height (BMI = weight(kg)/height(m)^2) as an indicator of prepregnancy weight. The pre-pregnancy BMI assists with recommendations for total weight gain ranges (in kilograms) and rates of recommended weight gain across the second and third trimesters (mean range in kilogram/week) (Figure 1) (Ministry of Health, 2014). Exceeding the guidelines during pregnancy (excess GWG) is a well-established predictor of long-term obesity, therefore reinforcing the importance of adherence to the guidelines (McKinley, Allen-Walker, McGirr, Rooney, & Woodside, 2018).

Figure 1

Recommendations for total and average rate of weight gain during pregnancy by pre-pregnancy BMI

Pre-pregnancy BMI (kg/m^2)	**Total weight gain range (kg)**	**Rates of weight gain 2nd and 3rd trimester (mean range in kg/week)**
Underweight (< 18.5)	12.5-18	0.51 (0.44-0.58)
Healthy weight (18.5-24.9)	11.5-16	0.42 (0.35-0.50)
Overweight (25.0-29.9)	7-11.5	0.28 (0.23-0.33)
Obese (≥ 30.0)	5-9	0.22 (0.17-0.27)

Source: (Ministry of Health, 2014).

Infant feeding mode, in particular, exclusive breastfeeding (EBF), has been considered an important factor in postpartum weight management (Ministry of Health, 2008; Rabi et al., 2021). However, findings are inconsistent amongst the literature. Some studies have found a positive association between infant feeding mode and postpartum weight loss, while others have reported no significant association (Lambrinou, Karaglani, & Manios, 2019).

Some suggest there is inadequate evidence to support the notion that breastfeeding leads to greater postpartum weight loss compared to alternative infant feeding methods. While breastfeeding may facilitate weight loss for some women, these findings cannot be generalised across all breastfeeding women (Neville, McKinley, Holmes, Spence, & Woodside, 2014).

The recommendations for BF set by WHO encourage BF initiation within the first hour of birth, then exclusively breastfeed (EBF) for the first 6 months of life. No other foods or liquids, including water, are recommended during this time. Despite the recommendations, global statistics show fewer than half of infants aged under 6 months old are EBF (World Health Organization, 2023). Many new mothers in a clinical setting have been encouraged to EBF as a means of effective infant feeding, but also to revert to pre-pregnancy weight. The underlying theory suggests breastmilk production requires high energy demands from both dietary intake and maternal fat stores (Butte & King, 2005; Ministry of Health, 2008). Due to mobilisation of maternal fat stores, weight loss has been reported to occur, however, producing highly variable results within and across population subgroups, even in those who are malnourished (Butte & Hopkinson, 1998; Ministry of Health, 2008).

Regardless of the recommendations in both NZ and international settings, breastfeeding initiation rates, duration, and exclusivity are suboptimal. Between the years 2010 to 2018, the global prevalence for EBF for less than 6 months was 45.7% (Zong, Wu, Zhao, Magnussen, & Xi, 2021). In NZ, only 16% of infants were EBF to 6 months, while 13% were breastfed to 2 years of age. Although most NZ children are breastfed initially, they do not meet the recommended guidelines for duration for either EBF or partial breastfeeding (PBF), therefore potentially disrupting the opportunity for the reduction of PPWR (Castro et al., 2017).

The postpartum body must undergo a series of dynamic changes to return to a similar state of its prepregnancy body. To measure these changes, comprehensive assessments are required to calculate weight change and body composition components, particularly fat mass (FM), and fat free mass (FFM). Because of unique body composition changes in the postpartum body, doubt is raised at the accuracy and applicability of common body composition techniques that have been validated in other population groups (Biddulph, Holmes, Kuballa, Carter, & Maher, 2022). Commonly used assessment methods amongst the postpartum population include air displacement plethysmography (ADP), otherwise known as BOD POD, and dual x-ray absorptiometry (DXA). Both of which are recognised as reference methods for body composition research. However, they are highly expensive and labor intensive when it comes to large sample sizes. Bioelectrical impedance analysis (BIA) is a more affordable and practical approach for the analysis of body composition than BOD POD and DXA, making it more desirable for laboratory and field-based settings. Studies from USA and Canada have investigated BIA performance against DXA as a reference method (Barry, Martin, Chandler-

Laney, Carter, & Worthington, 2022; Maran et al., 2022), however, the validation of BIA against BOD POD has not been comprehensively investigated. Despite the literature investigating postpartum body composition, a consensus is yet to be made on whether BIA is valid method of assessment to use within this population (Biddulph et al., 2022).

1.2 Purpose of the study

There has been limited understanding of how maternal body composition changes over the postpartum period, one NZ study has examined the effects of feeding mode on infant's body composition (Castro et al., 2022). No other NZ studies have investigated the effects of infant feeding mode on maternal body composition across the first year postpartum.

This study was a secondary analysis based on the data collected from the Mother and Infant Nutrition Investigation (MINI) study, an observational longitudinal cohort study among NZ women in the first year postpartum. The aim for this study is to describe maternal body composition changes and explore possible effects of infant feeding mode on body composition at 3-, 6-, and 12-months postpartum.

Furthermore, this thesis sets out to evaluate whether BIA, in comparison to BODPOD, provides similar estimations of body composition in this postpartum population.

1.3 Aims and Objectives

1.3.1 Aim

To explore patterns in maternal body composition 3-, 6-, and 12-months postpartum in conjunction with infant feeding mode, and to validate BIA in assessing body composition in this population.

1.3.2 Objectives

1. Describe body composition changes amongst New Zealand breastfeeding women 3-, 6-, and 12-months postpartum.

2. Describe the effect of infant feeding mode at 3 months postpartum on body composition.
3. Validate the use of BIA against BODPOD to measure of body composition changes in breastfeeding women 3-, 6-, and 12-months postpartum.

1.3.3 Hypotheses

1. Body composition variables will show significant changes at 3MPP, 6MPP, and 12MPP.
2. At 3MPP, women in the EBF group will have lower total body weight and total fat mass, when compared to women in the MF group.

3. BIA will be a valid measure of postpartum body composition when compared to the results of the BODPOD.

1.4 Thesis structure

There are four chapters in this thesis. Chapter one includes an introduction of the research and its justification. This will also comprise of the aim, objectives, and hypotheses. The second chapter reviews the literature on body composition changes, its contributing factors, and various anthropometric measurement techniques. Chapter three is presented as a manuscript for publication and includes an abstract, introduction, methods, results, discussion, and reference to relevant appendices. This is formatted in accordance with the requirements of the thesis. The conclusions and recommendations based on the study findings are outlined in chapter four. The appendices include supplementary results, questionnaires and materials used in conducting research.

1.5 Researcher's contributions

Researchers	Contribution
Sally Bodle *Principal researcher*	Responsible for thesis topic and design, thesis writing, reviewing, editing and submission. Responsible for statistical analysis and interpretation.
Associate Professor Louise Brough *Primary supervisor*	Assisted and supported data analysis. Assisted in result dissemination. Revised and approved the thesis chapters and manuscript.
Dr. Ying Jin *Secondary supervisor*	Assisted and supported data analysis. Assisted in result dissemination. Revised and approved the thesis chapters and manuscript.

Chapter 2: Literature Review

2.1 Research Question and Introduction to Literature Review

Despite extensive research and recommendations for weight management during pregnancy, the postpartum period remains understudied. The overarching purpose of this literature review is to answer the question of what is currently known about body composition changes among breastfeeding women in NZ over the first year postpartum. Specifically, the role of factors that influence postpartum body composition such as infant feeding status, energy balance and physical activity, prepregnancy body mass index (BMI), gestational weight gain (GWG), ethnicity, and sociodemographic factors will be explored. As well, the literature related to methodologies for assessment of body composition, breastfeeding patterns, and other factors that influence body composition among postpartum women will be reviewed.

2.2 Literature Review Methods

Studies in this review were searched between November 2022 – September 2023. Research studies and literature were identified from online databases including Massey University Discover, Scopus, Google Scholar, PubMed, and Science Direct. In addition, the Ministry of Health (MOH) databases and Statistics New Zealand were utilised for NZ statistics and current recommendations and guidelines. A number of search terms were generated from the study's purpose, aims and objectives. These key terms are presented in Table 1, and were searched both independently or in a combination using "and" and "or" search functions. Key recommendations and reviews from organisations such as the New Zealand MOH and World Health Organization (WHO) were also included in this review.

Table 1

Key search terms used during research

"postpartum"	"air displacement plethysmography"	"fat mass"	"maternal body composition"
"maternal"	"bioelectrical impedance analysis"	"fat free mass"	"bod pod"
"postnatal"	"validation"	"anthropometry"	"body mass index"
"body composition"	"weight retention"	"women"	"weight change"
"breastfeeding"	"weight loss"	"measurement"	"infant feeding"
"lactating"	"weight gain"	"guideline"	"feeding practises"
"New Zealand"	"obesity"	"recommendation"	
"recommendation"	"overweight"	"clinical practise guidelines"	

2.3 Maternal Body Composition Changes in the First Year Postpartum

2.3.1 Relevant factor: infant feeding mode

Research investigating postpartum weight retention (PPWR) or weight change in the first year postpartum has produced varying results (Table 3). Further, the majority of the literature is specific to the breastfeeding population, while only one study to the researchers' knowledge does not collect infant feeding data when investigating postpartum body composition changes (Cho et al., 2011).

Of nine studies investigating postpartum weight or body composition change in the first year following birth, eight were longitudinal studies (Butte, Hopkinson, Ellis, Wong, Puyau, et al., 1997; Cho et al., 2011; Hatsu, McDougald, & Anderson, 2008; Kac, D'Aquino Benicio Maria, Valente Joaquim, & Velásquez-Meléndez, 2003; Mullaney et al., 2016; Rabi et al., 2021; Tahir et al., 2019; To & Wong, 2009), while one was a preliminary study (Chou, Chan, & Moyer-Mileur, 1999). Most of the studies investigated the association between infant feeding mode and body composition, while only four studies investigated the association between breastfeeding and PPWR (Baker et al., 2008; Haiek, Kramer, Ciampi, & Tirado, 2001; Kac et al., 2003; Tahir et al., 2019). One study did not collect data on breastfeeding and therefore just

measured the changes in body composition on its own (Cho et al., 2011). Studies were conducted across Korea (n=1), Morocco (n=1), USA (n=4), China (n=1), Brazil (n=1), and Ireland (n=1). Sample size ranged between 20 (Cho et al., 2011) to 470 women (Mullaney et al., 2016). Time of postpartum body composition measurements varied in length with final measurements taking place between 6 weeks (Cho et al., 2011) and 12 months (Butte, Hopkinson, Ellis, Wong, Puyau, et al., 1997; Rabi et al., 2021). Baker et al. (2008) measured weight change at 6 months and continued past the first year for the second measurement at 18 months (about one and a half years).

Of the seven studies investigating the association between breastfeeding and maternal body composition changes (Table 2), only two studies found that breastfeeding contributed significantly to weight loss after childbirth (Hatsu et al., 2008; Rabi et al., 2021). In particular, fat loss was higher for women who exclusively breastfed until 6 months (30% of participants) over any other pattern of breastfeeding (Rabi et al., 2021). Rabi and colleagues investigated the effects of breastfeeding in 70 lactating Moroccan women using stable isotopic dilution technique. Measurements were carried out at 1-, 3-, 6-, 9-, and 12-months postpartum. The study found that all indicators of excess fat (body mass index, percent fat mass, and fat mass index) returned to their pre-pregnancy categories around the ninth month postpartum. The most significant losses occurred in the first three months following birth, with the exception of BF%, which decreased significantly around the ninth month. Furthermore, women who were EBF returned to a normal fat mass compartment from the third month, whereas for non EBF women, it is only after the ninth month that this observation occurred. These results suggest fat loss among EBF women was higher and took a shorter time compared to other infant feeding patterns. FFM did not seem to be affected by any infant feeding pattern (Rabi et al., 2021).

Similarly, Hatsu et al. (2008) observed a BF% loss among EBF mothers that was statistically significant at 12 weeks postpartum, but not for MF mothers. Despite MF mothers having higher BF% loss across three time points (4-, 8-, 12-weeks), a repeated measures analysis showed that the rate and trend of BF% loss among EBF mothers was statistically significant over time. Fat mass showed a similar trend to BF%. For other markers of maternal weight and body composition changes, no statistical significance was observed between breastfeeding groups due to the small sample size (n=24) and short study duration of 12 weeks. Regardless, the authors concluded weight loss among EBF mothers occurred at a higher and faster rate than MF mothers (Hatsu et al., 2008).

Other studies found greater, but non-significant weight loss to occur in EBF women who adhered to breastfeeding guidelines of EBF for the first 6 months, when compared to MF or FF women. These findings remained non-significant even after adjusting for confounding factors such as parity (Haiek et al., 2001; Kac et al., 2003; Mullaney et al., 2016; Tahir et al., 2019; To & Wong, 2009), pre-pregnancy BMI (Haiek et al., 2001; Hatsu et al., 2008), and gestational weight gain (Haiek et al., 2001; Tahir et al., 2019).

Results differed for Baker et al. (2008), who assessed postpartum body weight change at 6 and 18 months postpartum in 26,846 breastfeeding women in Denmark. The study showed that breastfeeding exclusively for 6 months and to any extent for 12 months, made an independent contribution to the reduction in PPWR at 6 and 18 months postpartum. Notably, Baker's findings were regardless of prepregnancy BMI and other potential confounding factors of parity and GWG (Baker et al., 2008). The remaining studies investigating breastfeeding on PPWR demonstrated no significant effect between infant feeding groups.

2.3.3 Relevant factor: Energy balance

Postpartum weight change in the postpartum period may be influenced by energy intake. In an observational cohort study, the influence of energy intake and energy expenditure on postpartum body weight was investigated among 37 women with obesity (BMI $\geq$ 30 kg/m^2). Changes in body composition was measured at 6 and 12 months postpartum via BODPOD. Energy intake was calculated using the energy intake-balance method as the sum of total daily energy expenditure (TDEE) and the changes in energy stores. To determine postpartum energy intake, TDEE at 12 months postpartum was used and the changes in energy stores were calculated as changes in FM and FFM at 0-6 months postpartum and from 6-12 months postpartum. Results showed women who had PPWR increased their energy intake (+250kcals) at 6 and 12 months postpartum, whereas those that had postpartum weight loss (PPWL) decreased their intake (-350kcals) during the same periods.

To determine energy intake during pregnancy, energy expenditure was calculated as the mean of TDEE at early (13-15 weeks) and late (35-37 weeks) gestation, and changes in energy stores as changes in FM and FFM at early and late gestation. During pregnancy, both PPWR and PPWL women had similar dietary intakes (2793kcal and 2846kcal, respectively). Following

pregnancy, PPWL women decreased their intake by -356kcal at 0 to 6 months and -327kcal at 6 to 12 months. In comparison, PPWR women increased their energy intake by 262kcal and at 259kcal during the same time periods.

Therefore, weight gain from early pregnancy to 12 months postpartum was the result of weight change after pregnancy as opposed to weight gain during pregnancy. PPWR was characterised by marked changes in FM and increased energy intake, and was independent of GWG (Most et al., 2020).

2.3.4 Relevant factor: Pre-pregnancy BMI

There are inconsistent findings around the influence of prepregnancy BMI on postpartum weight changes. Currently, the Institute of Medicine (IOM) recommends weekly GWGs to be in accordance with maternal prepregnancy BMI. Prepregnancy BMI is classified in line with WHO BMI references as underweight (<18.5kg/m^2), normal weight (18.5-24.9kg/m^2), overweight (25.0-29.9kg/m^2), and obese (>30kg/m^2) (Yaktine & Rasmussen, 2009).

Among eight studies investigating the effect of prepregnancy BMI on PPWR, six were longitudinal studies (Haugen et al., 2014; Jayasinghe et al., 2022; Kac & Benício, 2004; Linné et al., 2004; Montpetit, Plourde, Cohen, & Koski, 2012; Subhan et al., 2019), one was a meta-analysis (Rong et al., 2015) and one was a descriptive comparative study (Huang, Wang, & Dai, 2010). Sample sizes ranged from n=59 (Montpetit et al., 2012) to n=56,101 women (Haugen et al., 2014). Final postpartum measurements were taken between 6 weeks (Montpetit et al., 2012) and 15 years (Linné et al., 2004). PPWR was calculated as the difference between prepregnancy weight, and weight at various postpartum measurement points in all studies.

In majority of studies, prepregnancy BMI had no influence on PPWR, except for three studies (Huang et al., 2010; Jayasinghe et al., 2022; Montpetit et al., 2012). Huang et al (2010) found that Taiwanese women defined with a prepregnancy weight in the underweight category (BMI <18.5 kg/$m^{2)}$, were more likely to retain >1 kg of body weight at 6 months postpartum. Additionally, nearly half of the women in underweight and normal weight prepregnancy groups gained more than their recommended 14kg of gestational weight. The overweight and obese prepregnancy BMI groups had less GWG and retained the least weight at 6 months postpartum (1.67kg and -0.29kg) (Huang et al., 2010). Jayasinghe et al. (2022) reported similar findings where prepregnancy BMI was significantly associated with postpartum body weight at three

and 6 months. Women who were obese prepregnancy, had the lowest levels of weight fluctuation during pregnancy and retained less weight postpartum compared to normal weight and overweight prepregnancy BMI groups. Montpetit et al. (2012) carried out a hierarchical multiple regression analysis to explore predictors of PPWR. GWG and energy intake significantly correlated with PPWR, and when prepregnancy BMI was tested for correlation, it emerged as an important predictor ($p = 0.22$).
All three studies found a higher prepregnancy BMI (overweight 25-29.9 kg/m^2 and obese > 30 kg/m^2) categories were associated with lower PPWR (Huang et al., 2010; Jayasinghe et al., 2022; Montpetit et al., 2012).

A commonly reported limitation across studies was the use of self-reported prepregnancy weight used to calculate BMI, risking measurement error.

2.3.5 Relevant factor: Excessive gestational weight gain

Weight gain during pregnancy in excess of the IOM recommendations, is associated with negative health consequences for both mother and baby (Jayasinghe et al., 2022). The prevalence of excess GWG among pregnant women is alarmingly high. In a systematic review including over 1 million women globally, 47% had GWG in excess of the IOM guidelines (Goldstein et al., 2017). Excessive GWG is consistently reported as the strongest predictor for PPWR, and the subsequent risk factor for development or persistence of obesity in women (Berezowsky & Berger, 2021). The literature shows that women who exceed the recommended GWG set by the IOM, tend to retain a significantly higher amount of weight postpartum compared to those who gain weight within or below the recommendations (Haugen et al., 2014; Subhan et al., 2019; Yaktine & Rasmussen, 2009).

In a large Norwegian observational cohort study, 36,197 women were investigated to establish the effects of excess GWG on PPWR and at 6 and 18 months postpartum. Women who experienced GWG in excess of the IOM guidelines, resulted in PPWR of more than 2kg across all prepregnancy BMI classes at 6 months, however most women returned to their prepregnancy BMI class at 18 months, independent of GWG (Haugen et al., 2014). In contrast, an observational study based in the US, investigating 774 women to identify risk factors for PPWR and the relationship of the PPWR and obesity at 1 year postpartum, it was confirmed

that excess GWG was a risk factor for PPWR, and subsequently, those with increased PPWR had greater likelihood of becoming obese at 1 year postpartum (Endres et al., 2015).

2.3.6 Relevant factor: Physical activity

Interventions involving physical activity, particularly when paired with diet, have been shown to reduce postpartum weight retention (van der Pligt et al., 2013). Postpartum women in New Zealand are guided by the Eating and Activity Statements for New Zealand Adults (2020) and are recommended to achieve 30 minutes of moderate-intensity physical activity on most, if not all days of the week.

The relationship between physical activity and weight loss in the postpartum period has been studied (LeCheminant et al., 2014; Öhlin & Rössner, 1996). However, these studies are not specific to the breastfeeding population. Few researchers have identified whether physical activity alone has any effect on postpartum body composition or weight loss, as results may be confounded by diet or a combination of both diet and exercise. Seven studies have looked at the relationship between physical activity and body composition changes in postpartum women who are breastfeeding (Bertz, Winkvist, & Brekke, 2015; C. Lovelady, 2011; C. A. Lovelady, Lonnerdal, & Dewey, 1990; Cheryl A. Lovelady, Nommsen-Rivers, McCrory, & Dewey, 1995; McCrory, Nommsen-Rivers, Mole, Lonnderdal, & Dewey, 1999; Østbye et al., 2009; Zourladani et al., 2015). Six studies were randomised controlled trials (RCT), and one was a case control study. Of the randomised controlled trials, the sample sizes ranged from n=16 (C. A. Lovelady et al., 1990) to n=450 (Østbye et al., 2009).

In these trials, the intervention period was commenced between 4 weeks to 8 months postpartum with the exercise intervention lasting between 12 - 18 weeks. This is with the exception of one study (McCrory et al., 1999) which lasted only 11 days to establish the short-term effects of dieting compared with dieting plus exercise. In this trial, the short intervention period was the result of the required 35% reduction in energy for both the diet and diet + exercise groups. Exercise for all RCTs varied, but generally fell within 30-60 minutes, 3-6 days per week, between 60-70% of predicted heart rate. The exercise prescription consisted mostly of aerobic exercise or self-administered exercise, with two including resistance training (LeCheminant et al., 2014; Zourladani et al., 2015).

All seven research studies including the six randomised controlled trials and one case control study concluded that exercise had no significant effect on postpartum weight loss in both the short and long term. In the studies with an exercise intervention group and a control group, there was no significant weight loss between these groups. When a diet intervention group was included, there was significant weight loss. When investigating diet plus exercise compared to diet alone, the majority showed no additional weight loss with the addition of exercise. For example, in a sample of 68 postpartum Swedish women, the diet and exercise group lost less weight than the diet alone group, demonstrating exercise alone did not result in significant weight loss (Bertz et al., 2015).

Despite the lack of significant weight loss among exercising postpartum women, there was significant decrease of body fat percentage as a result of exercise among some studies (C. A. Lovelady et al., 1990; McCrory et al., 1999; Zourladani et al., 2015). Exercise was shown to improve body composition in postpartum women by lowering fat mass and conserving fat-free mass. For example in an RCT (McCrory et al., 1999), body fat percentage was lowered and FFM was conserved in the diet plus exercise group, as opposed to diet alone. Diet and exercise resulted in lower body fat in comparison to the control or diet alone. Whereas one study found significant decreases in body fat percentage at all time points (6-8 weeks, 12-14 weeks, 18-20 weeks) for both the exercise group and the control group. However, there was no significant difference between the exercise group and the control group at any time point. FFM remained constant throughout the study for both groups (Cheryl A. Lovelady et al., 1995).

2.3.7 Relevant factor: Ethnicity and its role in postpartum weight change

Ethnicity has emerged as an important potential predictor of PPWR. Women from minority ethnic groups are disproportionately affected by PPWR (Kent-Marvick, Cloyes, Meek, & Simonsen, 2023). In a large (n=642) multi-ethnic population-based cohort study, women with an ethnic origin from South Asia, the Middle East, and Africa had a significantly higher PPWR than Western European women. The ethnic differences in PPWR remained, despite adjusting for potential confounding factors of age, parity, GWG, and education status (Waage et al., 2016). Several other studies report minority ethnic groups differences in PPWR persist after adjusting for covariates (Avorgbedor et al., 2022; Headen, Davis, Mujahid, & Abrams, 2012). Minority ethnic groups in New Zealand as of 2018 include Māori (16.5%), Asian (15.1%) and Pacific peoples (8.1%) (Environmental Health Intelligence New Zealand, 2018). There is only

one multi-ethnic study available in New Zealand that focuses on pregnancy related weight gain (GWG) (Naiqiso, Okesene-Gafa, Christensen, & McCowan, 2019) and limited New Zealand studies investigate the influence of ethnicity groups on PPWR.

Table 2

Summary of characteristics of studies examining postpartum body composition changes

Authors (year)	*BF group? (Classification)*	*Measurement of interest*	*Time of postpartum measurement*	*Sample size*	*Method of measurement*	*Did EBF/BF have a significant impact on body composition compared to non-EBF/BF?*	*Were analyses adjusted for prepregnancy weight or BMI?*	*Were analyses adjusted for GWG*	*Were analyses adjusted for parity?*
Butte *et al.* (1997)	BF Non-BF	FM FFM	3 mo 6 mo 12 mo	35	TBW UWW SF TBK DXA TOBEC	N	N	N	N
Cho *et al.* (2011)	N/A	BW BMI FM FFM TBW ECW	2 days 2 wk 6 wk	41	BIA	N/A	N	N	N
Chou *et al.* (1999)	BF Non-BF/FF	BW FM FFM SF	1 wk 6 wk 12 wk	20	DXA SF	N	N	N	N
Hatsu *et al.* (2008)	EBF MF	BW BF%	2 wk 4 wk 8 wk 12 wk	24	BOD POD	Y	Y	N	N
To *et al.* (2009)	BF Non-BF	BW BMI BF%	6-8 mo	104	BIA	N	N	N	Y
Rabi *et al.* (2021)	EBF Non-EBF	BMI TBW FFM FM	1 mo 3 mo 6 mo 9 mo	34	Deuterium oxide	Y	N	N	N

		BF%	12 mo						
Mullaney *et al.* (2016)	EBF MF FF	BW BMI FM FFM TBW	4 mo	470	BIA	N	N	N	Y

Table adapted from (Neville et al., 2014)

Abbreviations: BF = breastfeeding, EBF = exclusive breastfeeding, MF = mixed feeding, FF = formula feeding, PPWR = postpartum weight retention, BMI = body mass index, GWG = gestational weight gain, BW = body weight, TBW = total body water, ECW = extracellular water, , SF = skinfold, BF% = body fat percentage, UWW = underwater weighing, TBK = total body potassium, DXA = dual-energy X-ray absorptiometry, TOBEC = total body electrical conductivity.

Table 3

Summary of characteristics of research examining postpartum weight retention

Authors (year)	*BF group? (Classification)*	*Measurement of interest*	*Time of postpartum measurement*	*Sample size*	*Method of measurement*	*Did EBF have a significant impact on PPWR compared to non-EBF?*	*Were analyses adjusted for prepregnancy weight or BMI?*	*Were analyses adjusted for GWG*	*Were analyses adjusted for parity?*
Baker *et al.* (2008)	EBF MF	PPWR	6 mo 18 mo	26,846	Scales	Y	Y	Y	Y
Kac *et al.* (2003)	EBF MF	PPWR	2 wk 2 mo 6 mo 9 mo	271	Scales	N	N	N	Y
Haiek *et al.* (2000)	EBF MF FF	PPWR	Various until 9 mo	236	Beam balance	N	Y	Y	Y
Tahir *et al.* (2019)	EBF MF FF	PPWR	1 mo 3 mo 6 mo	338	Scales	N	Y	Y	Y

Table adapted from (Neville et al., 2014)

Abbreviations: BF = breastfeeding, EBF = exclusive breastfeeding, MF = mixed feeding, FF = formula feeding, PPWR = postpartum weight retention, BMI = body mass index, GWG = gestational weight gain
*PPWR calculated by subtracting the reported prepregnancy weight from the observed weight at each measure point.

2.4 Postpartum Weight Management Guidelines

Despite there being many clinical practice guidelines and recommendations for weight management throughout all stages of the reproductive period – preconception, pregnancy, postpartum, and inter-conception - specific guidelines for the postpartum period show a need for further development. Guidelines for postpartum weight management in New Zealand are limited. The most recent guidelines specific to postpartum weight management were published in 2008 as part of the Food and Nutrition Guidelines for Healthy Pregnant and Breastfeeding Women (Ministry of Health, 2008). Within these guidelines, it is not recommended to have rapid weight loss of more than 0.5kg per week while breastfeeding. Instead, women are to expect weight loss to be slow, taking up to 12 months before there is a return to prepregnancy weight. Recommendations regarding the average extra daily energy requirement for breastfeeding women is 2000-2100 kJ per day. The recommended energy intakes for breastfeeding are based on the slow weight loss of around 5 kg during the first six months postpartum. No further specific guidelines are provided.

Since 2008, the New Zealand Eating and Activity Guidelines for Healthy Adults were updated to include advice for pregnant and breastfeeding women (Ministry of Health, 2020). Guidelines specific to postpartum women involve the inclusion of a healthy diet and regular, moderate-intensity physical activity, specifically 30 minutes on most if not all days of the week. EBF until around 6 months and continuing breastfeeding to 24 months and beyond is recommended as a supportive tool for weight management.

More recent guidelines have been released by Australia (Ball, de Jersey, Parkinson, Vincze, & Wilkinson, 2022), Canada (Piccinini-Vallis, Adamo, Bell, Pereira, & Nerenberg, 2020), and India (Balsarkar, 2022). Australian guidelines recommend healthcare professionals support women to return to prepregnancy weight by six months post-partum, and no later than 12 months postpartum. For those remaining above a healthy weight in the postpartum period, active support for further weight reduction prior to subsequent pregnancy is recommended. Postpartum women in Australia are guided by nutrition guidelines for all adults, which includes eating a wide variety of foods from the five food groups (Ball et al., 2022).

In India, overweight or obese postpartum women should be advised to decrease body weight to a BMI of 23kg/m^2. Weight loss of 0.5kg per week is recommended, resulting in 5-10% of

clinically significant weight loss over a 6 month period. Postpartum women with a BMI in the normal range (18.5-22.9kg/m^2), but who have substantial PPWR (>4.5kg when comparing to prepregnancy body weight) should be motivated to achieve their prepregnancy body weight within 12 months postpartum (Balsarkar, 2022). New Zealand, Australia, and India guidelines encourage postpartum women to exclusively breastfeed to 6 months postpartum, followed by breastfeeding to 12 months and beyond as a supportive tool for weight management in postpartum women.

The Canadian Adult Obesity Clinical Practise Guidelines are specific to women with obesity. Obese women (BMI > 30 kg/m^2) are recommend to enter pregnancy at a lower BMI (< 30kg/m^2), targeting weight gain during the entire pregnancy of 5-9kg, and returning to at least the prepregnancy BMI within a year after delivery (Piccinini-Vallis et al., 2020).

2.4.1 Breastfeeding Guidelines and Definitions

Breastfeeding is optimal for providing infants with the nutrients they need for healthy growth and development. As defined by the Healthy Eating Guidelines for New Zealand Babies and Toddlers (0-2 years old), exclusive breastfeeding (EBF) means that from birth, an infant receives only breast milk (from the breast or expressed) and prescribed medicines, where necessary. Partial breastfeeding is defined as the infant receiving some breast milk (from the breast or expressed) and some infant formula (Ministry of Health, 2021b). Additional definitions include full breastfeeding (FBF) in which the infant has taken only breast milk and a small amount of water or prescribed medicines in the past 48 hours. Formula feeding (FF) is defined as the infant having no breast milk but has had infant formula with or without food in the past 48 hours (Ministry of Health, 2008). The New Zealand Ministry of Health recommends that infants should be exclusively breastfed from birth until around six months of age, with continuance of breastfeeding until two years and beyond.

EBF is encouraged till at least 6 months because of the nutrition, antibodies, enzymes, hormones and growth factors it provides which cannot be replicated in artificial infant formulas (Victora et al., 2016). The complex makeup of breastmilk helps protect infants against infection by transferring antibodies from mother to infant, enhancing the infant's immature immune system through the mothers mature immune system (SACN, 2018).

2.4.2 Breastfeeding in New Zealand

As of 2022, 78% of infants were exclusively breastfed at hospital discharge. This is a slight increase in the EBF rate for 2022 (+0.45%), compared to rates of EBF in 2021 and 2020 (77.47% and 77.48% respectively). EBF among Māori infants is also positively trending, with an increase of 0.75% putting them 3.38% above the national average (77.93%). However, Māori infants continue to have the highest rates of formula feeding at this time at 5.13% despite the downwards trend since 2020 (NZBA, 2022).

The Growing Up in New Zealand (GUiNZ) study has reported that New Zealand compares favourably with other developed countries for breastfeeding initiation. However, a large proportion of children do not achieve the international or national recommendations for duration of breastfeeding or continuation of breastfeeding. Castro et al. (2017) analysed data from 6685 singletons enrolled in the Growing up in New Zealand study to describe breastfeeding initiation and duration for infants in New Zealand. Results showed the median duration for breastfeeding in New Zealand was 7 months of age, ranking in the lowest quartile for this particular indicator on the global scale. Children were exclusively breastfed for a median duration of four months, with 16% being breastfed exclusively at six months, and 37% breastfed for over 12 months (Castro et al., 2017).

2.4.3 Barriers to breastfeeding

Breastfeeding initiation, duration, and cessation among women are affected by a number of factors. Maternal age, education, pregnancy planning, parity, socioeconomic status (SES), ethnicity, knowledge and belief, and partner and family support are all factors consistently reported for their impact on breastfeeding (Beggs, Koshy, & Neiterman, 2021; Hernández-Cordero et al., 2020; Snyder et al., 2021). In the GUiNZ study, Māori and Pacific women were less likely to initiate breastfeeding. Maternal age of $\geq$ 20 years, tertiary education, planned pregnancy, and primiparity were all factors that increased the likelihood of breastfeeding for $\geq$ 6 months (Castro et al., 2017).

A number of qualitative studies in New Zealand have investigated the motivators and barriers for breastfeeding among Māori women (Glover, Waldon, Manaena-Biddle, Holdaway, & Cunningham, 2009; Manhire et al., 2018). Manhire et al. (2018) examined predictors of

extended breastfeeding duration among a predominantly Māori (70.5%) population (n=197). The study found key predictors for extended duration to be strong support from a partner or her mother, an intended duration of breastfeeding, and being an older mother. Alternatively, key predictors for a shorter duration included pacifier use, cigarette smoking, alcohol use, and living in highly deprived areas. The authors concluded that Māori women were more likely to breastfeed for a shorter duration than non-Māori women. Glover et al. (2009) reported similar findings for 59 Māori women from major metropolitan areas and provincial cities across NZ. Barriers for breastfeeding duration had additional factors including poor access to antenatal education and support, and the return to work being a key reason for stopping BF early.

Additionally, women with lower SES tend to initiate breastfeeding less often than women of higher SES. Foster et al. (2023) investigated the association between BF duration and mothers PPWR status at 4-10 years among 2,144 American women, and evaluated whether associations were affected by SES. The study found lower SES women were less likely to breastfeed to six months, or breastfeed altogether when comparing to their higher SES counterparts. Despite the lower long-term PPWR for those that breastfeed to six months compared to those that did not, the association did not differ by SES (Foster et al., 2023).

2.5 Body composition measurement methods and it's validation

2.5.1 Overview of body composition measurement methods

A variety of body composition assessment methods exist and fall between reference, laboratory, and field methods (Heymsfield, 2005). Reference methods provide the most accurate assessment of indirect body composition measurement and include magnetic resonance imaging (MRI), and computed tomography (CT), dual energy X-ray absorptiometry (DXA), underwater weighing (UWW), air displacement plethysmography (ADP) (Heymsfield, 2005). These methods are often the criterion against which other techniques can be compared for agreement.

Laboratory methods are extensively used as the standard for research as well as in the clinical setting. These include the gold standard methods of hydro densitometry (underwater weighing), ADP (via BODPOD machine), and isotope dilution (TBW). DXA is considered the laboratory reference standard to which field methods are validated against. The most commonly used field techniques are skinfold thickness (SFT), bio-impedance analysis (BIA),

and body mass index (BMI) (Norgan, 2005). Field methods are often inexpensive, portable and require little training for assessment and therefore , are favourable methods to adopt in large studies.

Assessment methods are grouped by the number of body compartments they measure. The two-compartment (2C) model is the simplest assessment approach for measuring body composition where body weight is divided into fat-free mass (FFM) and fat mass (FM) (Kuriyan, 2018). Commonly used approaches of the 2C model include ADP, hydro-densitometry, BIA and TBW (Kuriyan, 2018). Three-compartment (3C) models categorise FFM into lean tissue mass (LTM) and bone mineral content (BMC). FFM is made up of total body water (TBW) and the remaining solids; minerals and protein, fat-free dry mass (FFDM). Dual-energy X-ray absorptiometry (DEXA/DXA) is a commonly used 3C model (Kuriyan, 2018).

2.5.2 Air displacement plethysmography (BOD POD)

BOD POD is an air displacement plethysmography (ADP) system used for measuring body composition and is based on the 2-compartment model. The system contains a measuring chamber and a reference chamber that are linked by an upright diaphragm, which is perturbed to induce small pressure changes between the two chambers (Fields, Goran, & McCrory, 2002). The basic principle of ADP is to determine total body volume, where the participants volume is equal to the volume of the empty chamber minus the volume of the chamber containing the participant. The pressure-volume relationship at a fixed temperature is calculated by Poisson's Law to determine the volume of the participant in the measuring chamber. After being calibrated with a known volume, the participant will enter the chamber to be weighed, wearing swimwear and a swimming cap. The participant must remain in the chamber for 2 minutes, breathing normally before carrying out a breathing exercise for residual gas collection (Ackland et al., 2012).

The BOD POD provides several advantages over other established body composition analysis methods. These include its quick, comfortable, safe, and non-invasive measurement procedures, while accommodating for a large range of subject types (children, adults, elderly, obese, disabled persons) (Fields et al., 2002; Fields, Gunatilake, & Kalaitzoglou, 2015). Disadvantages of ADP may present in the obese population. Due to ADP being based on the

2C model, the assumption of a constant FFM density may be violated in the extremely obese population and lend to error for the estimation of body composition parameters when using this method (Hames, Anthony, Thornton, Gallagher, & Goodpaster, 2014).

ADP via BOD POD has been used in studies assessing the effect of breastfeeding on postpartum body composition (Hatsu et al., 2008; Motoyasu, Berger, Anderson, Smith, & Birch, 2017). Motoyasu et al (2017) investigated differences among 77 healthy postpartum women by infant feeding mode (BF or FF) and the effects on body weight and percent body fat (BF%). BF% was assessed via BOD POD at 2, 8, and 16 weeks postpartum. The study concluded that FF mothers were initially heavier, and retained more weight and BF% from 2 to 16 weeks. Additionally, a lower percentage of FF mothers lost weight and BF% during this time period when compared to their BF counterparts. Findings were similar for 24 healthy postpartum women from Athens-Clarke County, USA (Hatsu et al., 2008). Hatsu also assessed maternal body composition and BF% between EBF and MF mothers. Having used BOD POD to measure maternal weight changes over the first 12 weeks postpartum, it was observed that EBF promoted greater weight loss than MF among mothers.

2.5.3 Bio-electrical Impedance Analysis in the assessment of postpartum body composition

Bioelectrical impedance analysis (BIA) is a widely used method for body composition estimation in many different clinical conditions such as cancer, obesity, and sarcopenia (Ceniccola et al., 2019). It has also been used in health and fitness areas, and in clinical trial settings (Kushner, 1992; Kyle et al., 2004b). The principle of the BIA method is to determine electrical impedance (resistance) of a non-invasive electrical current passing through the body (Kyle et al., 2004a). Due to varying water content between body compartments of fat mass (FM) and fat-free mass (FFM), the electrical conductivity will travel at different speeds and produce an estimate of body composition. From the determined impedance, measurements of fat mass and fat-free mass can be estimated.

There are several BIA devices available to use, and are classified by the number of electrical frequencies: single frequency (SF-BIA), and multi-frequency (MF-BIA). Regardless of the number of frequencies, the precision level has been shown to be very good, with just 1-2% variability between repeated measures (Kyle et al., 2004a).

Both the advantages and disadvantages of the BIA method have been extensively reviewed. The primary advantages include being safe for repeated measures, low costs, portability, and quick and non-invasive method (Ceniccola et al., 2019).
As for disadvantages, Buchholz et al. (2004) found BIA to be sensitive to environmental and physiologic conditions. Impedance appears to be affected by recent exercise, fluid and food consumption, room and skin temperature (Buchholz, Bartok, & Schoeller, 2004). Changes in hydration status was a disadvantage discussed extensively throughout the literature, as well as the need for a specific equation depending on the population being assessed (Ceniccola et al., 2019; Kyle et al., 2004b).

There is growing use of BIA to quantify body composition in postpartum women (Cho et al., 2011; Ota et al., 2008; To & Wong, 2009). Cho et al. (2011) utilised BIA for the measurement of maternal body composition in the postpartum period. The study aimed to evaluate the changes in maternal body composition postpartum using BIA amongst 41 healthy postpartum women in Korea. The measure of body composition was achieved by MF-BIA, at 2 days, 2 weeks, and 6 weeks postpartum. While hydration status at 2 days postpartum, particularly in women who delivered their baby via caesarean section was a potential source of bias, there was no significant difference in body composition components between vaginal or caesarean deliveries (Cho et al., 2011).

2.5.4 Validation of body composition assessment methods used in postpartum women

Appropriate and reliable measures of maternal body composition are required to inform health and lifestyle interventions focused on postpartum women. Pregnancy drives a shift in fat metabolism and distribution, as well as alterations in residing hydration of tissues from pregnancy and early post-partum stages. Consequently, body compositions can vary greatly between postpartum women, raising doubt in using common body composition assessment techniques that are validated amongst other population groups (Biddulph et al., 2022).

Several studies have been carried out to validate body composition assessment methods against reference methods within the postpartum population (Barry et al., 2022; Butte, Hopkinson, Ellis, Wong, & Smith, 1997; Ellegård, Bertz, Winkvist, Bosaeus, & Brekke, 2016; Lof & Forsum, 2004; Maran et al., 2022; Papathakis, Rollins, Brown, Bennish, & Van Loan, 2005).

Models and techniques included anthropometry (skinfolds, body weight, and height) (N=4), hydrometry (isotype dilution) (N=4), densitometry (N=1), bioelectrical impedance analysis (N=5), and DXA (N=4). Most of the studies included healthy, lactating, postpartum women, with exceptions of one including overweight/obese women (Ellegård et al., 2016), and another including HIV+ postpartum women (Papathakis et al., 2005). Sample size of studies ranged from N=21 (Lof & Forsum, 2004) to N=132 postpartum women (Maran et al., 2022). The timing of measurements ranged from 2 weeks to 15 months postpartum, with two studies carrying out a series of longitudinal measures over the first year (Butte, Hopkinson, Ellis, Wong, & Smith, 1997) and year and a half postpartum (Ellegård et al., 2016).

In nearly all studies validating impedance analysis against various reference methods (Table 4), impedance analysis was deemed acceptable for use within the healthy postpartum population with strong agreement to reference methods. The only exception was for the overweight or obese postpartum population where impedance devices (BIS – bioimpedance spectroscopy and MF-BIA) underestimated FM when compared to measures assessed by DXA (Ellegård et al., 2016). However, in Barry et al.'s (2022) research validating BIA against DXA, using healthy postpartum women (N=21) and height and weight matched non-postpartum controls (N=21), BIA underestimated FM and overestimated FFM when compared to DXA. However, when assessed for longitudinal changes, BIA did not differ significantly from longitudinal measures by DXA (Barry et al., 2022).

BOD POD has rarely been used for body composition measurement among postpartum women. Despite the technique being fast and simple, BOD POD's accuracy is still being validated in lactating women at this time (Biddulph et al., 2022). In a non-postpartum population, Hurst et al. (2016) investigated the validity of BIA against ADP (conducted in BOD POD) and DXA for the measurement of body fat percentage among 166 men and women. BIA showed excellent relative agreement to ADP and DXA, however showed wide limits of agreement. It also underestimated body fat percentage by 2%. DXA showed excellent relative agreement with ADP, but also had wide limits of agreement. However, all three methods showed good reliability within the adult population (von Hurst et al., 2016).

Table 4

Summary of characteristics of studies examining validation of body composition methods in the postpartum population

Author (year)	Objective	Study Population	Study design	Body composition assessment methods	Timing of measurements	Method comparison	Validity	Relevant findings	Strengths	Limitations
Butte et al (1997)	To compare 2-, 3-, 4- compartment models and test for an effect of pregnancy or lactation on hydration, density, or potassium content of FFM	N = 35 healthy postpartum women lactating and non-lactating, USA.	FFM and FM estimated by nine body composition models at three time points were compared using repeated measures ANOVA. As were changes in FFM and FM at 3-6mo and 6-12mo postpartum.	Two-component (TBW, UWW, SF, TBK, DXA/TOBEC), three-component (TBW and UWW – Fuller 3, Siri 3), four-compartment (TBW, UWW and BMC – Fuller 4), TBW by deuterium dilution	3 mo 6 mo 12 mo	Systematic differences observed among BC models in FM and FFM measurements, but longitudinal changes over time did not differ significantly among models.	No effect on pregnancy/lactation on postpartum composition of FFM, 2-C models of body composition are acceptable for use in postpartum women.	The rank order from lowest to highest estimate of FM was TOBEC, TBW, Fuller 3, Siri 3, Fuller 4, UWW, SF, TBK, DXA. By 3 months, the relative composition of FFM had returned to within normal range. Changes in FFM and FM did not differ significantly between models.	Numerous models used: systematic differences noted between models	Not all lactating: prevalence was 27/35, 22/35, 9/35 at 3, 6, 12 months.
Barry et al (2022)	To examine the performance of multi-frequency, segmental BIA, and compare estimates of FFM and FM between BIA and DXA in two groups of women.	N = 42 women (21 postpartum, 21 non-postpartum), Alabama.	FM and FFM estimated by BIA were compared with DXA for 1-, 2-month postpartum women and non-postpartum controls. FM and FFM were also compared between BIA and DXA and the mean differences were compared using ANOVA.	BIA, DXA	1 mo 4 mo	Compared with DXA, BIA overestimated FFM and underestimated FM in postpartum women at 1-, and 4-months. But longitudinal changes in FM and FFM by BIA did not differ significantly from DXA.	BIA may be best suited for the assessment of relative changes in body composition in postpartum women rather than to assess absolute FM or FFM at any given time point.	No significant difference in the performance of BIA's standard equations for FM and FFM between postpartum women and non-postpartum controls.	Examined the performance of contemporary bioimpedance analyzer in postpartum women. Included height- and weight-matched controls.	Small sample size. Racial homogeneity. No non-lactating postpartum women were included.
Maran et al (2022)	To assess the agreement of %BF between SFT and BIA with DXA in the postpartum.	N = 132 postpartum women, Canada.	Agreement between %BF from SFT and BIA during postpartum, and the agreement between SFT, and BIA measures to DXA were evaluated using a Bland Altman plot.	SFT, BIA, DXA	6 mo postpartum	BIA and SFT showed good agreement and were significantly correlated. BIA ad good agreement with DXA and was significantly correlated. SFT and DXA had a weaker agreement but was still significantly correlated.	SFT and BIA had good agreement with DXA in the postpartum period. BIA and SFT are preferable tools in the postpartum period.	While there is a strong agreement for both BIA and SFT with DXA, there is large limits. This indicates that thought the results are similar, they are not equivalent.	Used multiple quantitative adiposity measurement tools, a large sample size, ethnically homogenized.	Demographics used may reduce generalizability.
Papathakis et al (2005)	To determine the validity of BIS and anthropometric measurements to measure BC compared to the reference of the stable isotope dilution method.	N = 20 HIV+ and 48 HIV- lactating women, median age 24, low SES, South Africa.	Compared BIS and anthropometry ability to measure TBW with isotope dilution ($2H_2O$) to determine FM and FFM in HIV+ and HIV- lactating women.	TBW by BIS and isotope dilution for FM and FFM. Anthropometric measurements: BW, ht, BMI, MUAC, SFT	10 wk	BIS measurements correlated with $2H_2O$ in both HIV+ and HIV- mothers. SFT, BMI, and MUAC correlated strongly with $2H_2O$ method for FM, and for FFM in HIV- mothers only.	BIS has good agreement with reference $2H_2O$ method. SFT, MUAC and BMI also had good agreement with $2H_2O$, but not for FFM of HIV+ mothers.	TBW by BIS was 5-6% greater than the measurement by $2H_2O$ but was not a significant difference. Was considered acceptable.	Used $2H_2O$ as a reference method for measuring TBW.	Assessed HIV-infected women without severe immune suppression only.

	To describe body composition of HIV+ lactating women.									
Ellegard et al (2016)	To validate accuracy and precision of BIS and MFBIA with DXA and DLW for postpartum body composition assessment in overweight and obese women	N = 70 postpartum women, 35 overweight, 35 obese, Sweden.	Repeated measures of BC (FM, FFM, skeletal muscle mass, TBW) using reference methods and simple methodology (longitudinal and cross-sectional).	BW, Height, BIS, MFBIA, TBW by DLW (isotype dilution of D_2O and H_2O^{18}) & DXA (postpartum only)	3 mo (baseline) 6 mo (12-week intervention) 15 mo (1 year follow up)	Both BIS and even more so MFBIA underestimated FM and overestimated FFM and TBW.	The most accurate and precise estimation of TBW compared with DLW was obtained by using 73% of FFM as assessed by DXA.	BIS underestimated FM, overestimated BW compared with DXA and DLW, but accurately estimates muscle mass and changes in BC. MFBIA underestimate FM compared with DXA and overestimate TBW compared with DLW. Impedance devices underestimate FM in overweight and obese women.	Used accepted reference measures. Used three repeated measures.	Systematic bias by measuring in supine position. Bioimpedance devices used in study are too imprecise for individual evaluation.
Lof et al (2004)	To evaluate BIS estimates of ECW, ICW, and TBW before, during, and after pregnancy.	N = 21 healthy women, with healthy pregnancies, and lactating in postpartum period, Sweden.	Methodological study comparing BIS measurements of EWC, ICW, and TBW with reference methods through pregnancy and postpartum.	BIS, isotope dilution, bromide dilution	Before pregnancy 14 wk gestation 32 wk gestation 2 wk postpartum	Average estimates of ICW by BIS were in good agreement with corresponding reference data.	BIS may be useful for estimating average ICW, as well as changes in ICW, in groups of women during reproduction.	BIS measurements of ECW, ICW, and TBW in postpartum agreed with reference data.	Used reference methods.	BIS assumes that the body consists of five cylinders.

Table adapted from (Biddulph et al., 2022)

Abbreviations: BW = body weight, %BF = body fat percentage, BC = body composition, BMI = body mass index, FFM = fat free mass, FM = fat mass, TBW = total body water, UWW = underwater weighing, SF/SFT = skinfold/skinfold thickness, TBK = total body potassium, DXA = dual X-ray absorptiometry, TOBEC = total body electrical conductivity, BIA = bioelectrical impedance analysis, BIS = bioimpedance spectroscopy, MF-BIA = multifrequency bioimpedance analysis, DLW = doubly-labelled water, MUAC = mid-upper arm circumference, BMC = bone mineral content, ICW = intracellular water, ANOVA = analysis of variance

2.6 Summary of Literature Review

Pregnancy and the retention of excess weight gained during pregnancy predisposes women to overweight and obesity risks later in life. Appropriate weight management is necessary to reduce the risk of overweight and obesity related disorders such as cardiovascular disease, type 2 diabetes mellitus, hypertension, obstructive sleep apnea, stroke, some types of cancers. Postpartum women are recommended to return to their prepregnancy weight within the first year post childbirth. Despite the abundance of international guidance around postpartum weight management, NZ guidance remains fairly minimal and generalised. The management of postpartum weight is multifactorial and individual to each woman. The most common factors investigated in this population group include GWG, prepregnancy BMI, BF practices, ethnicity, energy balance, and physical activity.

There is limited research investigating maternal body composition changes during the first year postpartum among NZ women. Assessing the impact of infant feeding mode on weight change variables such as total weight, fat mass, free fat mass, and body fat percentage is important for managing and monitoring weight in the postpartum period and beyond for reproductive women in NZ.

Chapter 3: Manuscript: Body composition changes in the first year postpartum among breastfeeding women living in Palmerston North, New Zealand. Mother and Infant Nutrition Investigation (MINI) Study

3.1 Abstract

Background: Postpartum weight retention (PPWR) is the retention of the weight gained during pregnancy, where retention of excess weight can put reproductive women at increased risk of overweight and obesity and the associated health consequences. Infant feeding mode is one of the many factors that have been investigated for its influence on PPWR and body composition change in the postpartum. However, research remains conflicting due the multifactorial nature of postpartum weight loss and gain. Bioelectrical impedance analysis (BIA) has been used within the postpartum population, though it's validation is still being studied. The present study aimed to explore patterns in maternal body composition at 3-, 6-, and 12-months postpartum in conjunction with infant feeding mode, and to validate BIA in assessing body composition in this population.

Methods: This was a secondary analysis based on the data collected from the Mother and Infant Nutrition Investigation (MINI) Study. In this observational longitudinal cohort study, breastfeeding women in Palmerston North, New Zealand. Women (n=87) who were healthy, breastfeeding, and living in New Zealand completed three body composition assessment measurements at 3-, 6-, and 12-months postpartum (3MPP, 6MPP, 12MPP). Prepregnancy weight was self-reported in the main maternal questionnaire at 3MPP. Total weight (TW), fat mass (FM), fat-free mass (FFM), and body fat percentage (BF%) were measured via BIA and air displacement plethysmography (BODPOD). Body composition changes were analysed using descriptive statistics. Infant feeding mode at 3MPP (Exclusive breastfeeding (EBF) or mixed feeding (MF)) and its effect on body composition changes was assessed using analysis of variance (ANOVA). Pearson's correlation was used to assess the validation between BIA and BODPOD measurements, as well as cross-classification agreement.

Results: Mean maternal age was 31.5 ± 4.2 years. The mean prepregnancy body mass index (BMI) tended to be higher for the MF group (26.2kg/m2), compared to the EBF group (23.8kg/m2), though the difference was not significant. Mean (geometric, 95% CI) prepregnancy weight was significantly lower at 66.8 (64.0, 69.8) kg than the mean (geometric, 95% CI) total weight at 12MPP (68.9 (65.3, 72.8) kg) (p = 0.046), resulting in a mean

(geometric, 95% CI) weight retention of 3.14 (2.1, 4.7) kg. All participants showed significant changes at 3MPP, 6MPP, and 12MPP for all measures of body composition. TW, FM, and BF% showed a significant reduction over time points ($p < 0.001$), while FFM showed a significant increase at 6MPP ($p < 0.001$). At 3MPP 83% of participants were EBF. There were significant differences between EBF and MF groups for FM, TW, BF%, but not for FFM. However, when combining time and infant feeding mode, there was no statistical significance. Body composition measurements via BIA and BOD POD were strongly associated ($p < 0.001$), and were classified into the same tertiles, with k-statistic agreement levels between 0.5 (moderate) to very good (> 0.80).

Conclusion: Our study highlights the trend in reduction of TW, FM, and BF%, while preserving FFM. However, there was no significance observed between infant feeding groups. Despite these trends, there was PPWR prevalent among our participants. At 12MPP, women had, on average, gained weight at 12MPP, relative to their prepregnancy weight. BIA showed high correlations to BODPOD across all measures of body composition, strengthening its use within the postpartum population.

3.2 Introduction

Postpartum weight retention (PPWR) comprises the retention of weight gained during pregnancy, and as a result, poses significant risks to the long-term health of reproductive women (Berezowsky & Berger, 2021). Obesity, a common consequence of PPWR, has been linked to various health conditions and comorbidities such as cardiovascular disease, type 2 diabetes mellitus, hypertension, stroke, and some cancers (Samnang et al., 2023). Furthermore, PPWR can adversely affect the outcomes of subsequent pregnancies, whereby women entering pregnancy overweight or obese are at a higher risk for preeclampsia, gestational diabetes, hypertension, and large-for-gestational age (LGA) infants (Luke, Kirby, & Wright, 2016).

In New Zealand (NZ) women, obesity prevalence has risen from 32% to 36% between 2020 to 2021 (Ministry of Health, 2021a). Multiple factors contribute to disparities in PPWR, including gestational weight gain (GWG), prepregnancy body mass index (BMI), parity, age, ethnicity, education, dietary habits, physical activity, and infant feeding patterns (Somvanshi, 2002). GWG more than the World Health Organization (WHO) recommendations is a key contributor to PPWR. Adequate GWG is essential not only to support fetal growth, but also for building fat stores that will eventually facilitate the demands of breastfeeding (Ministry of Health,

2008). GWG guidelines developed by the Institute of Medicine (IOM) are based on prepregnancy BMI to establish appropriate weight gains to support a healthy pregnancy (Yaktine & Rasmussen, 2009). Despite the guidelines, nearly half of women worldwide experience excessive GWG during pregnancy, a trend that can result in significant consequences (Goldstein et al., 2017).

Many researchers have highlighted infant feeding as a promising strategy for postpartum weight management due to its high energy requirements and mobilisation of fat stores accrued during pregnancy (Butte & King, 2005). While some studies, like Rabi et al. (2021) and Hatsu et al. (2008), suggest favorable outcomes for exclusively breastfeeding (EBF) mothers in terms of returning to their prepregnancy weight, others report inconclusive results (Haiek et al., 2001; Mullaney et al., 2016; Tahir et al., 2019). International guidelines developed by WHO recommend EBF for the first six months of life, and the introduction of nutritionally adequate and safe complementary foods at six months together with continued breastfeeding up to two years of age and beyond (World Health Organization, 2023). Although New Zealand lacks comprehensive postpartum weight management guidelines, recommendations for infant feeding are available, advising EBF for around the first six months and continued breastfeeding until two years and beyond (Ministry of Health, 2021b).

The existing literature on the impact of infant feeding on postpartum body composition/PPWR has produced mixed findings. Neville et al. (2014) conducted a systematic review that found insufficient evidence to directly link exclusive breastfeeding to postpartum weight changes compared to other infant feeding methods (Neville et al., 2014). Whereas Baker et al. (2008), established EBF for six months made an independent contribution to the reduction in PPWR at six months postpartum (6MPP) and 12 months postpartum (12MPP) among 26,846 mothers in Denmark (Baker et al., 2008). These discrepancies in study outcomes may be attributed to differences in study design, timing of measurements, study duration, sample size, self-reported prepregnancy weight, body composition measurement methods, and various infant feeding barriers such as intention to breastfeed, culture, age, education, support systems, and socioeconomic factors (Castro et al., 2017).

BOD POD is a body composition measurement method utilizing the air-displacement plethysmography (ADP) technique. Typically used as a reference method, BOD POD is accurate, non-invasive, and allows multiple readings over a short period of time. The BOD

POD method has been used in a small number of studies investigating postpartum body composition (Hatsu et al., 2008). Its validation within the postpartum population is still being studied (Biddulph et al., 2022). The bioelectrical impedance analysis (BIA) method uses an electrical current technique to calculate the impedance of the body. In general, BIA is advantageous due to its low cost, ease of use, portability, and efficiency. It has been used in many different populations and is increasing in use among postpartum women. Validating the BIA method in the postpartum population creates the opportunity for the method to be used in women's health clinics, within study participant homes, and in hospitals, further adding to the research of postpartum weight changes and PPWR.

Existing validation studies of BIA among the postpartum population have generally shown strong agreement with reference methods, such as the gold standard dual energy x-ray absorptiometry (DXA), in healthy postpartum women (Barry et al., 2022). While BIA has been validated in the non-postpartum adult population, in New Zealand, as a reliable method for body composition measurement (von Hurst et al., 2016), it can be challenging to apply to postpartum women due to fluctuations in hydration status, especially in the early postpartum stage and following a cesarean section (Ceniccola et al., 2019).

Although extensive research on weight patterns and body composition exists internationally, there is a notable gap in research addressing these issues in the postpartum period and the impact of infant feeding on PPWR in New Zealand. Despite the updated NZ Eating and Activity Guidelines including recommendations for pregnant and breastfeeding women (Ministry of Health, 2020), detailed guidance on managing PPWR remains limited (Dalrymple et al., 2018). There is a gap in the understanding of changes in body composition in the postpartum period, as most studies investigate body weight changes, rarely in a consecutive manner. This study aims to fill these gaps by describing changes in body composition among New Zealand women in the first year postpartum, investigating the influence of infant feeding status on body composition at 3MPP, and validating the use of BIA in the postpartum population.

3.3 Methods

3.3.1 Overview

The Mother and Infant Nutrition Investigation (MINI) is an observational longitudinal cohort study of breastfeeding women, living in Palmerston North, New Zealand, spanning the first year postpartum (Jin et al., 2020). Participants completed their first visit at 3 months postpartum, with additional follow up assessments at approximately 6- and 12-months postpartum. This study applies secondary analysis of data from the MINI study obtained during all three visits (3-, 6-, and 12-months).

3.3.2 Study population

Healthy breastfeeding mothers aged 16 years and over, who had given birth to a healthy term singleton infant 3 months prior were recruited. Recruitment spanned 19-months, beginning June 2016 and ending December 2017 and was promoted using posters placed at selected sites (general practitioner surgeries, maternal wards in hospitals, local community playgroups, ultrasound clinics, antenatal classes, and early childhood centres). Local newspapers and social media sites were also used. Local health professionals including midwives, childbirth educators, and lactation consultants were asked to familiarise their clients with the MINI study.

Women were eligible to participate, who resided within the Palmerston North region and were able to attend Massey University for scheduled visits. Mothers were excluded if they developed significant health problems such as medical complications during pregnancy or childbirth. Potential participants recorded an expression of interest online or via telephone or email. They were then provided with a study information sheet. Interested participants completed a screening questionnaire to assess eligibility. Following the procurement of written informed consent, participants were provided with an identifier code and were scheduled for their initial visit.

3.3.3 Ethics

All participants provided written consent. The MINI study was approved by the Health and Disability Ethics Committee (reference: 15/NTA/172) in December 2015.

3.3.4 Sample size

Sample size was calculated for the original MINI study aim (Brough, Coad, Jin, Skeaff, & Zhou, 2022) . The current study is a secondary data analysis.

3.3.5 Questionnaire

At the initial 3-month visit, mothers were asked general questions to determine demographic information including ethnicity, age, level of education, household size, and income. Information was also obtained about infant feeding patterns and obstetric details. Potential changeable information such as infant feeding status and general health was further questioned at the second and third visits. EBF was defined as infants being fed only breastmilk from birth, without any water, formula or liquid supplements (excluding essential medication). Mixed feeding was defined as infants receiving a mixed diet consisting of breastmilk, infant formula and /or complimentary food.

3.3.6 Anthropometric data

Maternal anthropometry measures were obtained at 3-, 6-, and 12-month study visits. Self-reported prepregnancy body weight and height was collected via the main maternal questionnaire at 3MPP. Height was assessed using a Toledo stadiometer and recorded to the nearest millimetre. Bioelectrical impedance analysis (InBody230, InBody Co) and air displacement plethysmography (BODPOD, COSMED SRL) were used to assess maternal body composition, including total body weight, fat mass, fat free mass, and body fat percentage. BOD POD is an accurate, non-invasive piece of equipment that has a brief measurement period which enables multiple readings over a short period of time (Hatsu et al., 2008). Conditions for measurement using BOD POD included; minimal clothing, wearing a swimming cap, before midday, after urination, normal room temperature (20 to 25º C), with no exercise, eating, drinking, or bathing/showering within two hours prior to measurement. Breastfeeding beforehand was also preferable.

On the day of testing, BOD POD manufacturer's instructions were followed for quality control where acceptance criteria was ±100mL of actual volume and standard deviation of ≤75mL.

3.3.7 Outcome variables

The main outcome variables were changes in maternal total body weight (kg), fat mass (kg), fat free mass (kg), and body fat percentage (%). Variables were assessed at 3-, 6-, and 12-months postpartum.

3.3.8 Independent variables

The covariates assessed at baseline were maternal educational attainment (tertiary education), ethnicity (Māori, Caucasian, Asian), household income (above annual median household income $75, 995 NZD for 2016), delivery type (vaginal/caesarean), parity (primiparous/multiparous), age, prepregnancy weight (kg), and prepregnancy BMI (kg/m^2).

Infant feeding status was assessed at each measurement time point (3-, 6-, and 12-months). The different infant feeding practices in this study included exclusive breastfeeding (EBF), mixed feeding (MF), or no breastfeeding.

3.3.9 Statistical analysis

Statistical analyses were performed using IBM SPSS Statistics version 24. Percentage and frequencies were used to describe categorical variables. Mean, median, standard deviation (SD), and percentiles (Q1 and Q3) were used to describe continuous variables. Continuous variables were tested for normality using Kolmogorov-Smirnov and Shapiro-Wilk statistics. Most of the data were not normally distributed, but became normally distributed once $\log^{10}$ transformed and are expressed as geometric means (95% CI). Data which could not be transformed to normal distribution were presented with median values and percentiles (Q1 and Q3).

Repeated measures ANOVA was used to examine the effect of infant feeding on maternal body composition changes at 3MPP, 6MPP, and 12MPP. Data was $\log^{10}$ transformed if required to achieve homogeneity of variance of the residuals. When data was compared by infant feeding method, the data collected at 3MPP was used. Results were reported as geometric means and 95% confidence intervals. A p-value of < 0.05 was considered significant. To validate BIA against BOD POD, Pearson's rank correlation was used. The levels of strength for Pearson's rank correlation were: 0.9-1.0 very strong correlation, 0.7-0.89 strong correlation, 0.4-0.69 moderate correlation, 0.1-0.39 weak correlation, and 0.0-0.1 negligible correlation (Schober & Schwarte, 2018). Cross-classification agreement was further investigated using the weighted

kappa (k)-statistic. Agreement levels for the k-statistic were: very good (>0.80); good (≥ 0.61-0.80); moderate (0.41-0.60); fair (0.21-0.40); and poor (< 0.20) (Masson et al., 2003).

3.4 Results

3.4.1 Descriptive Characteristics

The final analysis included 87 breastfeeding mothers at 3MPP, and followed up at 6MPP (n=78), and 12MPP (n=71). At 3MPP, the mean maternal age was 31.5 ± 4.2 (range: 22 – 41) years (Table 5). Most participants were Caucasian 76%, 10% were Māori, and 10% were Asian. Most participants achieved tertiary level education (78%). The majority had a vaginal delivery (78%), and 44% had delivered their first infant. At 3MPP, 83% infants were EBF; at 6MPP, 31% were EBF while 65% were MF; at 12MPP, only 46% infants were MF.

We observed a trend among the MF group of a higher median prepregnancy BMI of 26.2kg/m2 when compared to the EBF group (23.8kg/m2), further, mean prepregnancy weight trended higher for the MF group at 72kg, than for EBF at 65.7kg, although the differences were not significant ($p < 0.97$, $p < 0.177$).

Table 5

Participant demographic characteristics at 3MPP (n=87)

Maternal characteristics at 3MPP	*Total population (n=87)* N (%)	*Exclusive Breastfeeding (n=72)* N (%)	*Mixed feeding (n=15)* N (%)
Maternal age (years) Mean (± SD)	31.5 ± 4.2	31.5 ± 4.3	31.5 ± 3.7
Tertiary education	68 (78)	59 (82)	9 (60)
Ethnicity – Māori	9 (10)	-	-
Ethnicity – Caucasian	66 (76)		
Ethnicity – Asian	9 (10)		
Annual household income (Above median)†	54 (62)	-	-
Primiparity	38 (44)	31 (43)	7 (47)
Caesarean delivery	19 (22)	14 (19)	5 (33)
Height (cm) Mean (± SD)	165 ± 6.5	165 ± 6.3	165 ± 6.2
Prepregnancy weight (kg) Mean (geometric) (95% CI)	66.8 (64.0, 69.8)	65.8 (63.5, 69.4)	72.0 (64.1, 83.8)
Prepregnancy BMI (kg/m^2) Median (25th, 75th)	23.8 (21.2, 26.2)	23.8 (20.9, 25.9)	26.2 (21.8, 31.3)

† Median annual household income based on Statistics New Zealand was 75 995 New Zealand dollars for the year that ended June 2016 (Statistics New Zealand, 2018).

3.4.2 Changes in body composition

Across all participants, body composition variables showed significant changes across the three measurement time points (3MPP, 6MPP, and 12MPP, Table 6). Total weight, fat mass, and body fat percent showed a significant reduction over time across the three timepoints (p

<0.001). Mean fat free mass showed a significant increase of 0.54 (-0.01, 1.10) kg, over the 6 months period ($p < 0.001$).

3.4.3 Infant feeding status at 3MPP and the impact on body composition

For both infant feeding modes, (EBF and MF), there was a significant difference between infant feeding groups for FM, total weight, and BF%, but not for FFM. However, when combining time and infant feeding mode, no statistical significance was observed for all body composition measurements (Table 7).

3.4.4 Prepregnancy and postpartum body weight changes

The mean (geometric, 95% CI) estimated prepregnancy weight for study participants was 66.8 (64.0, 69.8) kg and the mean (geometric, 95% CI) total weight at 12MPP was 68.9 (65.3, 72.8) kg. Maternal prepregnancy weight was significantly lower than total weight at 12MPP ($p = 0.046$), with a mean (geometric, 95% CI) weight retention of 3.14 (2.1, 4.7) kg. However, there was no significant difference in weight change between infant feeding modes at 3MPP (EBF and MF), where mean weight change for MF was 4.4 (1.7, 11.3) kg and EBF 2.9 (1.8, 4.5) kg ($p < 0.085$).

A decreasing trend was found between 3 and 6 months postpartum, and 6 and 12 months postpartum for BODOD measurements of body fat percentage and fat free mass. Fat free mass reduced between 3 and 6 months but showed an increasing trend of 0.90kg between 6 and 12 months postpartum (Table 8).

Table 6

Mean body composition measurements via BOD POD at 3-, 6-, and 12-months postpartum

	Time postpartum (months)			
	(n=61)			
	Geometric mean (95% CI)			
Measure	3	6	12	p-value
Total weight (kg)	71.9 (68.2, 75.8)	70.3 (66.5, 74.3)	68.8 (65.0, 72.9)	< 0.001
FM (kg)	23.5 (21.1, 26.3)	22.0 (19.4, 24.9)	18.9 (16.1, 22.2)	< 0.001
BF (%)	33.7 (31.5, 35.9)	32.7 (30.2, 35.1)	29.7 (27.0, 32.5)	< 0.001
FFM (kg)	47.7 (46.1, 49.2)	47.2 (45.6, 48.8)	48.2 (46.6, 49.7)	< 0.001

ANOVA: repeated measures with time as factor and variable at different time points as measure. P-value taken from greenhouse-geisser.

Table 7

Changes in postpartum body composition components measured via BOD POD with respect to infant feeding status at 3MPP

Body composition variable	*Measurement point*	*Exclusive Breastfeeding at 3mo (n=52)*	*Mixed Feeding at 3mo (n=9)*	*Model p-value*		
		Mean (95% CI)	*Mean (95% CI)*	*Time*	*Infant feeding mode*	*Time*Infant feeding mode*
Total FM (kg)	3 months	22.6 (20.3, 25.3)	31.6 (22.1, 45.1)	**0.002**	**0.034**	0.552
	6 months	20.9 (18.4, 23.8)	30.6 (21.0, 44.6)			
	12 months	17.7 (14.9, 21.0)	26.7 (17.3, 41.1)			
Total weight (kg)	3 months	70.5 (66.9, 74.4)	83.6 (68.3, 102.4)	**<0.001**	**0.022**	0.828
	6 months	68.7 (65.1, 72.5)	81.9 (66.3, 101.1)			
	12 months	67.0 (63.3, 70.9)	80.0 (65.3, 97.9)			
FFM (kg)	3 months	47.2 (45.6, 48.8)	51.4 (45.5, 57.3)	0.199	0.063	0.959
	6 months	46.8 (45.2, 48.4)	50.6 (44.8, 56.4)			
	12 months	47.7 (46.1, 49.3)	51.9 (46.5, 57.4)			
Body fat %	3 months	33.0 (30.8, 35.3)	38.6 (32.0, 45.2)	**<0.001**	0.067	0.735
	6 months	31.8 (29.2, 34.4)	38.3 (31.6, 45.1)			
	12 months	28.6 (25.7, 31.6)	34.8 (26.6, 43.1)			

*Based on repeated measures ANOVA

Table 8

Changes in mean body composition measures between 3-6 months, 6-12 months, and 3-12 months

Measure	*Difference between time points Geometric mean (95% CI) 3-6months*	*6-12 months*	*3-12months*
Total weight (kg)	-1.47 (-2.06, -0.89)	-1.41 (-2.30, -0.52)	-2.88 (-3.98, -1.79)
FM (kg)	-1.10 (-2.00, 0.30) †	-2.31 (-3.13, -1.49)	-3.42 (-4.48, -2.37)
BF (%)	-1.01(-1.78, -0.23)	-2.96 (-3.81, -1.96)	-3.97 (-5.16, -2.77)
FFM (kg)	-0.36 (-0.87, 0.15)	0.90 (0.40, 1.40)	0.54 (-0.01, 1.10)

† FM (kg) BOD POD 3-6 months = Median (Q1, Q3)

3.4.5 Validation of BIA method against BOD POD

Table 9

Strength of association between body composition variables at 3-,6-,12-months postpartum by BIA and BODPOD

Measurement point	*Pearson's correlation (r-value)*	*p-value*
Total weight (kg)		
3 months	1.0	<0.001
6 months	1.0	<0.001
12 months	0.99	<0.001
Fat mass (kg)		
3 months	0.95	<0.001
6 months	0.95	<0.001
12 months	0.92	<0.001
Fat free mass (kg)		
3 months	0.93	<0.001
6 months	0.92	<0.001
12 months	0.93	<0.001
Body fat (%)		
3 months	0.91	<0.001
6 months	0.91	<0.001
12 months	0.93	<0.001

Measures of body composition were strongly associated ($p < 0.001$) with correlation coefficients ranging from 0.91 (BF% at 3MPP; BF% at 6MPP) to 1.0 (TW at 3MPP; TW at 6MPP) (Table 9).

Table 10

Cross-classification and weighted kappa between BOD POD and BIA

Body composition variable	*Correctly classified into the same tertile (%)*	*Classified into the adjacent tertile (%)*	*Grossly misclassified (%)*	*Weighted kappa statistic (p-value)*
Total weight (kg)				
3 months	86.8	13.2	0	0.803 (< 0.001)
6 months	95.7	4.3	0	0.934 (< 0.001)
12 months	95.2	4.8	0	0.921 (<0.001)
Fat mass (kg)				
3 months	86.8	13.2	0	0.802 (< 0.001)
6 months	88.6	11.4	0	0.823 (< 0.001)
12 months	85.7	14.3	0	0.763 (< 0.001)
Body Fat (%)				
3 months	71.1	28.9	0	0.565 (< 0.001)
6 months	83.8	16.2	0	0.751 (< 0.001)
12 months	87.3	12.7	0	0.789 (< 0.001)
Fat Free Mass (kg)				
3 months	78.9	21.1	0	0.684 (< 0.001)
6 months	70.0	30.0	0	0.535 (< 0.001)
12 months	71.4	28.6	0	0.518 (< 0.001)

The percentage of body composition variables classified into the same tertiles ranged from 70% (FFM at 6MPP) and 95.7% (TW at 6MPP) (Table 10). The weighted kappa statistic ranged from 0.518 (FFM at 12MPP), a moderate statistic, to 0.934 (total weight at 12MPP), a very good statistic when comparing to the k-statistic agreement levels.

3.5 Discussion

This is the first study in New Zealand (NZ) to investigate changes in body weight and body composition during the first year postpartum, particularly examining the influence of infant feeding mode. Additionally, the current study explores the validity of BIA as a method for

assessing body composition in postpartum women with respect to the reference method of air displacement plethysmography (BOD POD).

3.5.1 Body weight and body composition changes

In our sample of NZ women, we observed a significant decrease in total weight, fat mass, and body fat percentage at 3MPP, 6MPP, and 12MP, with a corresponding increase in fat-free mass over the same period. However, when adjusting for infant feeding mode at 3MPP (EBF or MF), there was a significant difference for total weight, FM, and BF%, but we found no significant difference between groups for fat free mass, regardless of time. The interaction between infant feeding mode and time at 3MPP, also did not yield statistically significant differences between groups for all variables of body composition at 3MPP, 6MPP, and 12MPP. These findings show a similar pattern to other studies (Haiek et al., 2001; Mullaney et al., 2016; To & Wong, 2009). Mullaney et al. (2015) found no significant difference in total weight at 4MPP between EBF and MF groups. The study found no relationship between infant feeding and postpartum changes in fat distribution. They did, however, find EBF women to have an increased FM and BF% between early pregnancy and 4MPP compared to non-EBF. Haiek et al. (2001) also found there to be no statistically significant differences in the rate of maternal weight loss between infant feeding groups of EBF and MF. MF mothers lost slightly more BF% than EBF mothers, despite the difference being non-significant. However, the trend in BF% was significant amongst EBF mothers but not for MF mothers. There was no significant difference between groups for both FM and BF%, though there was a trend in BF% loss in EBF mothers and not for MF mothers.

When investigating body weight changes in our cohort, we noted a significant decrease in total weight from 3MPP to 12MPP. A decreasing trend was found between 3 and 6 months postpartum, and 6 and 12 months postpartum for BOD POD measurements of body fat percentage and fat free mass. Fat free mass reduced between 3 and 6 months but showed an increasing trend of 0.90kg between 6 and 12 months postpartum. When looking at weight change between reported prepregnancy weight and maternal weight at 12MPP, we found a significantly higher weight gain with a mean PPWR of 3.14 (2.1, 4.7) kg, a finding that has been observed within the literature. Sichieri and colleagues (2003) found EBF was associated with a PPWR of 1kg at 12MPP, however when comparing to our study, not all women were EBF. The study additionally observed that duration of lactation was unrelated to the magnitude

of weight change (Sichieri, Field, Rich-Edwards, & Willett, 2003). Cho et al. (2011) used the BIA method to measure and evaluate changes in body composition in the postpartum period among 41 women. Total body weight decreased significantly from 2 days postpartum to 6 weeks postpartum, whereas PPWR from prepregnancy to 6 weeks postpartum was 4.43 ± 4.0 kg. Though PPWR in our study was less, it adds to the evidence that pregnancy and subsequent weight retention is a significant contributor to the risk for obesity 1 year postpartum and beyond (Endres et al., 2015).

3.5.2 Influence of Infant Feeding on Maternal Weight and Body Composition

Our results demonstrated weight loss primarily stemmed from loss of fat mass as opposed to fat-free mass between 3MPP and 12MPP. These findings align with previous research (Chou et al., 1999; Hatsu et al., 2008). The finding that weight loss primarily involved the reduction of fat mass without significant loss of fat-free mass between 3MPP and 12MPP is highly advantageous within the context of postpartum weight management. Preserving lean mass is essential for maintaining metabolic health, where low muscle fitness is associated with metabolic risk. Muscle mass and strength is inversely related to cardiovascular disease risk and mortality. Rapid weight loss can lead to the undesirable loss of fat-free mass, including muscle tissue (McCarthy 2021). Overall, despite significant decreases in body composition variables such as fat mass, body fat percentage, and total body weight from 3MPP to 12MPP, there was no significant difference between infant feeding status as measured at 3MPP (EBF and MF).

In addition to our findings regarding infant feeding mode and the effect on body composition changes, it is important to acknowledge the number of studies that have reported significant associations between postpartum body composition change or PPWR and various sociodemographic variables. These include age, parity, prepregnancy weight, dietary intake, physical activity, and ethnicity. Studies have consistently demonstrated the relevance of these variables in understanding postpartum body composition change and PPWR. For instance, it has been observed that with increasing maternal age and parity, the frequency of breastfeeding initiation decreased (Kitano et al., 2016) Ethnicity, too, plays a role where literature suggests an elevated weight trajectory following pregnancy in African American women compared to Caucasian women (Wang et al., 2023). Prepregnancy weight and BMI has been shown to influence PPWR where underweight women, or those with a low BMI prior to pregnancy were

more likely to have more PPWR than their overweight or obese counterparts (Huang et al., 2010; Jayasinghe et al., 2022).

3.5.3 Validity of BIA against BOD POD

There is growing interest in using BIA to assess body composition in the research, and clinical research setting due to its portability, ease of use, low cost, and absence of radiation. Equations for predicting body composition from BIA parameters are age, sex, and population specific. Therefore, there is a need to validate the BIA method within the postpartum population. Measuring body composition across pregnancy and into postpartum is difficult due to dynamic body composition changes and altered hydration status. Fluid shifts pose a concern for two compartment measurement models due to the assumption of constant hydration (Widen & Gallagher, 2014). In most of the current literature investigating the postpartum population, BIA is compared to dual energy x-ray absorptiometry (DXA), a gold standard method (Barry et al., 2022; Maran et al., 2022).

Barry et al. (2022) found BIA to be a suitable method to assess postpartum body composition using existing age-, race-, and sex-adjusted equations. Longitudinal changes in FFM and FM among 21 postpartum women were not statistically different between BIA and DXA. Furthermore, when comparing BIA measurements of the 21 postpartum women to the 21 height and weight matched non-postpartum controls, there was no significant difference, strengthening the evidence for use of BIA within the postpartum population. These findings were in line with the results observed by Maran et al. (2022) who demonstrated BIA showing good agreement with DXA in the early postpartum among a larger sample size of 181 postpartum women. However, comparative studies between BIA and BOD POD among the postpartum population remain limited.

In a non-postpartum NZ population, von Hurst et al. (2016) investigated the validity of BIA against BOD POD for the measurement of body fat percentage among men and women. BIA showed excellent relative agreement to BOD POD, however showed wide limits of agreement. It also underestimated body fat percentage by 2%. All methods showed good reliability within the adult population (von Hurst et al., 2016). In our study, BIA was suggested to be suitable for measuring body composition among postpartum women when compared to BOD POD, showing strong associations across all measures of body composition at all measurement

points. Cross classification revealed that most measurements aligned when comparing BIA to BOD POD, further strengthening the validity of BIA.

3.5.4 Strengths and limitations

This study should be interpreted considering its strengths and limitations. One key strength is the robust nature of the study. We measured all participants using both BIA and BOD POD (a gold standard reference method) at three postpartum time points to obtain a large amount of data relating to maternal body composition. Baseline data was collected in detail, including prepregnancy weight, height, ethnicity, educational attainment, and obstetric information. We also collected data on infant feeding mode at 3MPP, 6MPP, and 12MPP.

However, we acknowledge several limitations. First, our study is a secondary data analysis investigating the difference in weight change and body composition between EBF and MF mothers at 3MPP, 6MPP, and 12MPP. Only infant feeding mode at 3MPP was used in our analysis, as the entire population was either MF or EBF, and there were no non-breastfeeding controls. Second, the self-reported data on prepregnancy weight may have introduced some inaccuracy in our measures of prepregnancy BMI and total weight change during the postpartum period. Third, our inability to establish significant differences between groups may be due to our small sample size, especially the low proportion of MF at 3MPP. Participants in this study were highly educated and were predominantly Caucasian, and therefore not representative of the New Zealand population.

3.6 Conclusion

Our study's findings carry significance, as they highlight notable trends in the reduction of total body weight, fat mass, and body fat percentage, all while preserving fat free mass. These results are positive as they indicate a gradual rate of weight loss, avoiding the catabolism of lean muscle mass. While there was no significant difference observed between infant feeding groups, both EBF and MF groups experienced significant losses across the postpartum period. Despite these losses, our results showed PPWR was prevalent among our participants.
Moreover, our use of BIA showed high correlations across all measures of body composition when compared to the reference method BOD POD. The evidence for use of BIA among the postpartum population is positive for further research, due to its low cost, accessibility, and ease of use.

Overall, it is important to emphasise that while breastfeeding practices should be promoted for their numerous benefits, it should not be solely relied upon as a means for well-nourished women to return to their prepregnancy weight or to compensate for excessive gestational weight gain. Future New Zealand studies should consider a more diverse cohort and adjust for potential confounding factors such as dietary intake, physical activity, and ethnicity.

Chapter 4: Conclusion and Future Recommendations

4.1 Conclusion

Pregnancy is a risk factor for the development of obesity and the associated health consequences, which is why the postpartum period is a crucial time in a woman's life for weight management. Many factors influence the pattern and rate of weight change during this time including prepregnancy weight, excessive gestational weight gain, age, ethnicity, energy balance, and the pattern of infant feeding. Currently, New Zealand has limited research on body composition changes and PPWR in the postpartum period, and whether infant feeding mode has an impact. To date, international literature continues to show conflicting evidence that supports the implication of breastfeeding aiding postpartum weight loss, despite most guidelines suggesting a positive effect.

The aim of this study was to explore patterns in maternal body composition among NZ women at 3-, 6-, and 12-months postpartum in conjunction with infant feeding mode and to validate BIA in assessing body composition in this population. Postpartum women (n=87) were assessed for fat mass, fat free mass, body fat percentage, and total body weight. Our results showed a positive trend in PPWR of 3.14 (2.1, 4.7) kg. Despite this, there was significant weight loss from 3MPP to 12MPP of -2.88 kg. Fat mass, body fat percentage and total weight showed significant reductions over time, however when adjusting for infant feeding methods (EBF and MF), there was no significant difference between groups. Fat free mass showed no change over time, indicating a desirable effect in terms of body composition changes.

To assess validity of BIA against reference method BOD POD, Pearson's correlation and cross classification was used. All body composition variables measured via BIA and BOD POD showed strong associations all between 0.91 and 1.0. Cross classification with weighted kappa statistic showed all measurement variables were classified into the same and adjacent tertiles, with none being misclassified. These results further support the use of BIA among the postpartum population; however, a larger sample size would have a greater impact on the accuracy of results, particularly for fat free mass.

4.2 Strengths of the study

This is the first New Zealand study to investigate the weight change patterns, namely the patterns of total weight, fat mass, free fat mass, and body fat percentage among breastfeeding women in their first year postpartum. The study examines body composition components between 3- to 12-months postpartum, and the effect of infant feeding mode at 3-months (EBF or MF) on later measurement points at 6-months and 12-months. The study used two robust research methods to measure body composition, including the reference method and gold standard of BOD POD, and field method BIA. Three measurements were carried out via both methods at 3MPP, 6MPP, and 12MPP, in order to establish validity of the BIA method against BOD POD. In doing so, this study contributes to literature relating to the influence of infant feeding practices on postpartum weight management in New Zealand. Additionally, the assessment of body composition among postpartum breastfeeding women provides valuable data that can be used for evaluation against local and international figures.

4.3 Limitations of the study

There were a number of limitations within our study. First, the data on prepregnancy weight relied on self-reporting. Participants were asked to recall their prepregnancy weight at their initial baseline postpartum visit (3MPP). While this approach is commonly used in research, it introduces the potential for inaccuracies in the calculation of prepregnancy BMI, which may have further impacted our PPWR calculations.

Furthermore, the study had a relatively small sample size when compared to larger epidemiological studies. Additionally, there was a potential for selection bias as the majority of women within the sample were Caucasian, had acquired tertiary education, and generally from a high income-earning household. This demographic makeup does not necessarily represent the wider New Zealand population of Māori, Pacific Islanders, and Asian groups. Selection bias may affect the study outcome since women are more likely to initiate breastfeeding and continue to breastfeed past six months if they intended to breastfeed, have a higher household income, and have a tertiary education, whereas women are less likely if they are of Māori or Pacific ethnicity (Castro et al., 2017). Moreover, participants volunteering to take part in the study may have had pre-existing nutrition knowledge around breastfeeding, and may have been conscious of weight management during pregnancy and into postpartum.

Another significant limitation was the number of women who stopped EBF after the 3MPP measurement point. This prevented us from assessing potential differences in PPWR between women who engaged in mixed feeding versus those who exclusively breastfed for a longer duration of time. Additionally, due to our use of infant feeding mode at 3MPP where all women were either EBF or MF, we did not include non-breastfeeding controls.

Finally, while we had data on dietary intake, we were unable to investigate the impact of energy balance on postpartum body composition changes or PPWR as we did not have sufficient data on measured physical activity levels. Studies have shown the impact of these covariates on the rate of weight change and body composition changes, and are important to consider when discussing findings.

4.4 Research Recommendations

There are several recommended approaches resulting from the current study; these recommendations should be considered in future research to strengthen findings of body composition changes and the influence of infant feeding mode among postpartum women and improve the validity of the BIA method among the postpartum population.

- Further research involving a larger sample is required in order to investigate the effectiveness of infant feeding mode on postpartum weight and body composition change among New Zealand women. Other groups that should be involved in future studies include non-breastfeeding/formula feeding control participants, various ethnic groups, as well as people from low socioeconomic and educational backgrounds. Further research is needed to investigate the effect of infant feeding mode on body composition and weight changes amongst a more representative New Zealand postpartum population.

- Dietary intake and physical activity are factors that largely influence the rate of weight change among any population. Future studies should analyse these confounding factors to ensure an accurate analysis of body composition and weight changes among infant feeding groups.

- The effect of infant feeding should be investigated at multiple time points. In the current study, only infant feeding at 3MPP was investigated and therefore may have not been indicative of actual results due to the short time frame. Furthermore, NZ MOH recommends exclusive breastfeeding till 6MPP, followed by continued breastfeeding until two years and beyond.

- The use of BIA/BODPOD should be carried out among different population groups including the non-postpartum group, non-infant feeding groups, those with a higher or lower BMI, and those of different ethnicities i.e., Māori, Pacific Islander, Asian. Research has shown BIA can underestimate FFM in overweight or obese population groups. Additionally, it would be beneficial to compare results of non-postpartum women to postpartum women to establish whether hydration status influences the results of body composition changes among postpartum women.

- In reviewing the literature, we found New Zealand does not supply any current recommendations for postpartum weight management. The latest NZ based recommendations supporting postpartum women were published in 2008 (Ministry of Health, 2008). Since then, postpartum women are guided by the 'Eating and Activity Guidelines for New Zealand Adults', which includes a limited amount regarding weight management (Ministry of Health, 2020). More detailed information is required to support this population to achieve healthy weight management outcomes.

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Appendices

Appendix 1: ANZCTR Registration number

Dear Ying Jin,

Re: Mother and Infant Nutrition Investigation - Investigating micronutrient intake and status in mothers and babies, and their possible effects on thyroid function

Thank you for submitting the above trial for inclusion in the Australian New Zealand Clinical Trials Registry (ANZCTR).

Your trial has now been successfully registered and allocated the ACTRN: ACTRN12615001028594

Web address of your trial: http://www.ANZCTR.org.au/ACTRN12615001028594.aspx
Date submitted: 15/09/2015 1:15:17 PM
Date registered: 1/10/2015 10:29:21 AM
Registered by: Ying Jin

If you have already obtained Ethics approval for your trial, could you please send the ANZCTR a copy of at least one Ethics Committee approval letter? A copy of the letter can be sent to info@actr.org.au (by email) OR (61 2) 9565 1863, attention to ANZCTR (by fax).

mailto:info@actr.org.au

Please be reminded that the quality and accuracy of the trial information submitted for registration is the responsibility of the trial's Primary Sponsor or their representative (the Registrant).
The ANZCTR allows you to update trial data, but please note that the original data lodged at the time of trial registration and the tracked history of any changes made will remain publicly available.

The ANZCTR is recognised as an ICMJE acceptable registry (http://www.icmje.org/faq.pdf) and a Primary Registry in the WHO registry network (http://www.who.int/ictrp/network/primary/en/index.html).

If you have any enquiries please send a message to info@actr.org.au or telephone +61 2 9562 5333.

Kind regards,
ANZCTR Staff
T: +61 2 9562 5333
F: +61 2 9565 1863
E: info@actr.org.au
W: www.ANZCTR.org.au

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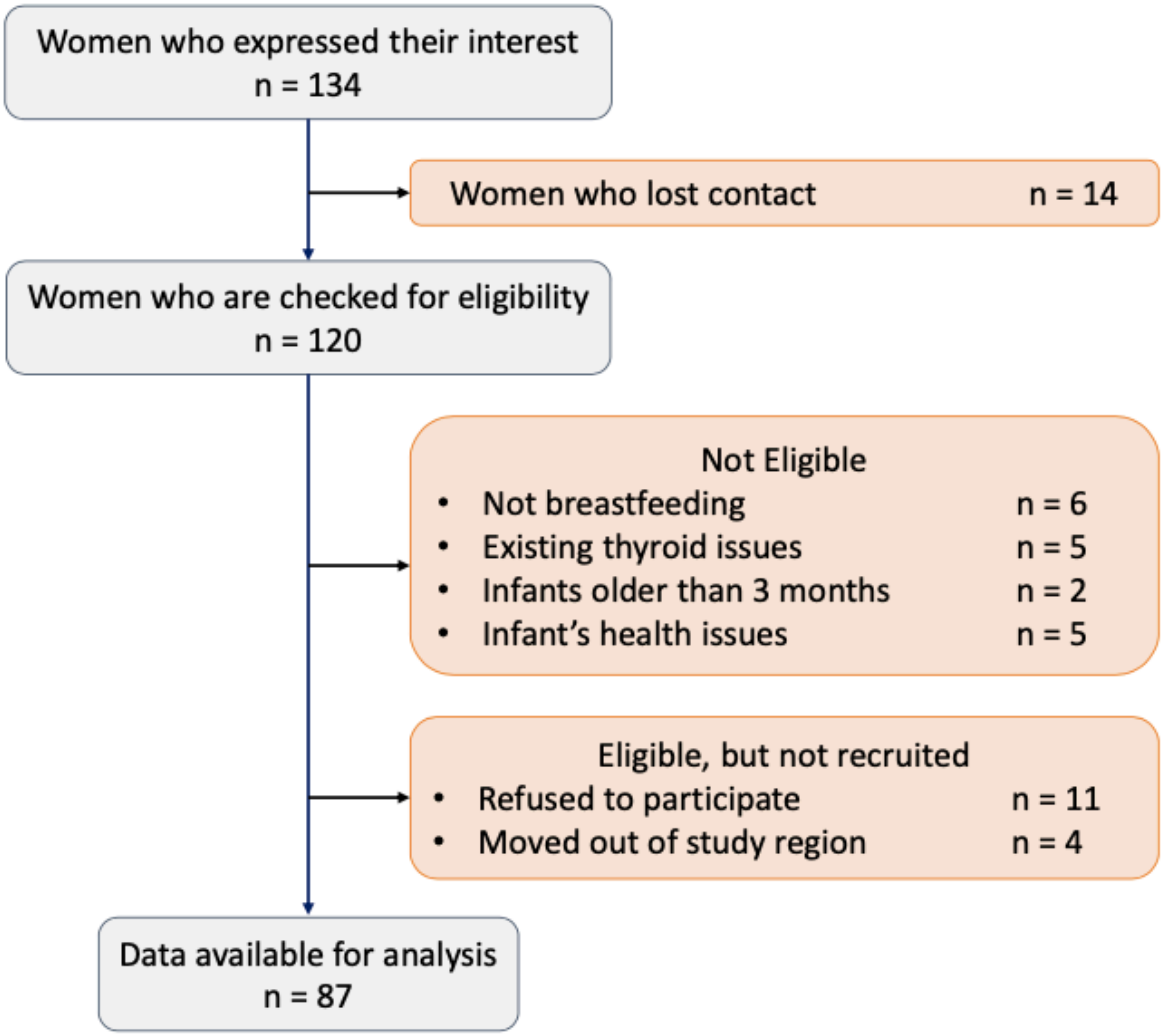
Appendix 2: Flowchart of study participation



Appendix 3: HDEC Letter

Health and Disability Ethics Committees
Ministry of Health
Freyberg Building
20 Aitken Street
PO Box 5013
Wellington
6011

0800 4 ETHICS
hdecs@moh.govt.nz

15 December 2015

Ms Ying Jin
School oF Food and Nutriton
Massey University
Private Bag 11222
Palmerston North 4442

Dear Ms Jin

Re:	**Ethics ref:**	**15/NTA/172**
	Study title:	Mother and Infant Nutrition Investigation

I am pleased to advise that this application has been *approved* by the Northern A Health and Disability Ethics Committee. This decision was made through the HDEC-Full Review pathway.

Conditions of HDEC approval

HDEC approval for this study is subject to the following conditions being met prior to the commencement of the study in New Zealand. It is your responsibility, and that of the study's sponsor, to ensure that these conditions are met. No further review by the Northern A Health and Disability Ethics Committee is required.

Standard conditions:

1. Before the study commences at *any* locality in New Zealand, all relevant regulatory approvals must be obtained.

2. Before the study commences at *a given* locality in New Zealand, it must be authorised by that locality in Online Forms. Locality authorisation confirms that the locality is suitable for the safe and effective conduct of the study, and that local research governance issues have been addressed.

After HDEC review

Please refer to the *Standard Operating Procedures for Health and Disability Ethics Committees* (available on www.ethics.health.govt.nz) for HDEC requirements relating to amendments and other post-approval processes.

Your next progress report is due by 15 December 2016.

Participant access to ACC

The Northern A Health and Disability Ethics Committee is satisfied that your study is not a clinical trial that is to be conducted principally for the benefit of the manufacturer or distributor of the medicine or item being trialled. Participants injured as a result of treatment received as part of your study may therefore be eligible for publicly-funded compensation through the Accident Compensation Corporation (ACC).

Please don't hesitate to contact the HDEC secretariat for further information. We wish you all the best for your study.

Yours sincerely,

Dr Brian Fergus
Chairperson
Northern A Health and Disability Ethics Committee

Encl: appendix A: documents submitted
appendix B: statement of compliance and list of members

Appendix A
Documents submitted

Document	*Version*	*Date*
PIS/CF	1	20 October 2015
Protocol	1	20 October 2015
Evidence of scientific review	1	20 October 2015
Survey/questionnaire: It is an index to provide an overview of all the questionnaires used in the study.	1	21 October 2015
Survey/questionnaire: V1_M2	1	21 October 2015
Survey/questionnaire: V1_M3	1	21 October 2015
Survey/questionnaire: V1_M4	1	21 October 2015
Survey/questionnaire: Health Screening Questionnaire	1	21 October 2015
Survey/questionnaire: V1_M5	1	21 October 2015
Survey/questionnaire: V1_H1	1	21 October 2015
Survey/questionnaire: V1_H2	1	21 October 2015
Survey/questionnaire: V1_H3	1	21 October 2015
Survey/questionnaire: V2_M1	1	21 October 2015
Survey/questionnaire: V2_M2	1	21 October 2015
Survey/questionnaire: V3_M1	1	21 October 2015
CV for CI	1	21 October 2015
Survey/questionnaire: Ages and Stages Questionnaires_Sample	1	21 October 2015
Investigator's Brochure	1	22 October 2015
Survey/questionnaire: V1_M1	1	22 October 2015
Survey/questionnaire: V2_H1	1	22 October 2015
PIS/CF for persons interested in welfare of non-consenting participant	1	22 October 2015
Application	1	-
PIS/CF: This is the updated version of the Information Sheet.	2	24 November 2015
PIS/CF: This is the updated version of Consent Form.	2	24 November 2015
Investigator's Brochure: This is the updated version of the Advertisement	2	24 November 2015

Appendix B
Statement of compliance and list of members

Statement of compliance

The Northern A Health and Disability Ethics Committee:

- is constituted in accordance with its Terms of Reference
- operates in accordance with the *Standard Operating Procedures for Health and Disability Ethics Committees*, and with the principles of international good clinical practice (GCP)
- is approved by the Health Research Council of New Zealand's Ethics Committee for the purposes of section 25(1)(c) of the Health Research Council Act 1990
- is registered (number 00008714) with the US Department of Health and Human Services' Office for Human Research Protection (OHRP).

List of members

Name	*Category*	*Appointed*	*Term Expires*
Dr Brian Fergus	Lay (consumer/community perspectives)	01/07/2012	01/07/2015
Dr Karen Bartholomew	Non-lay (intervention studies)	01/07/2013	01/07/2016
Dr Charis Brown	Non-lay (intervention studies)	11/11/2015	11/11/2018
Ms Susan Buckland	Lay (consumer/community perspectives)	01/07/2012	01/07/2016
Ms Shamim Chagani	Non-lay (health/disability service provision)	01/07/2012	01/07/2016
Dr Christine Crooks	Non-lay (intervention studies)	01/07/2013	01/07/2018
Dr Kate Parker	Lay (consumer/community perspectives)	11/11/2015	11/11/2018

Unless members resign, vacate or are removed from their office, every member of HDEC shall continue in office until their successor comes into office (HDEC Terms of Reference)

http://www.ethics.health.govt.nz

Appendix 4: Health Screening Questionnaire

MASSEY UNIVERSITY
COLLEGE OF HEALTH
TE KURA HAUORA TANGATA

Code: _____

MINI Study - Mother and Infant Nutrition Investigation

Date of visit: _____ Day_____ Month_____ Year

First name_____ Surname_____

Primary Contact Address

Street number and name:

Suburb:

City:

Postcode [if known]:

Primary Contact Phone Number(s)

Email address

Secondary Contact information

Street number and name:

Suburb:

City:

Postcode [if known]:

Subject Identifier

This page will be detached from remainder of the questionnaire at the end of the interview. Confidential information will be stored separately.

Participants information

MASSEY UNIVERSITY
COLLEGE OF HEALTH
TE KURA HAUORA TANGATA

Code: _____

MINI Study - Mother and Infant Nutrition Investigation

Date of visit: _____ Day_____ Month_____ Year

Health Screening Questionnaire

Thank you volunteering to take part in this study. I would like to ask you a few questions to check that you are a suitable subject and provide you with an opportunity to ask any questions that you may have about the study.

What is your age?

Are you currently breastfeeding?

When was your baby born?

Do you have any contagious blood borne disease, eg. Hepatitis A or HIV?

Do you currently have any medical conditions?

Have you ever been diagnosed with thyroid disease such as thyroid enlargement or goiter/ hyperthyroidism/ hypothyroidism?

If yes, are you currently receiving any treatment or consuming medication containing iodine? Or, are you now fully recovered?

Are you taking iodine contain supplements due to other reasons rather than pregnancy or lactation?

Are you taking any other medication? ***If yes, can you please indicate the type or name of the medication(s) that you are taking?***

Does your baby have any health complications, eg. Preterm?

Preferred method of contact:

Appendix 5: MDHB Approval Form for Research Activity

MidCentral District Health Board

MDHB APPROVAL FORM FOR RESEARCH ACTIVITY

Research Practice Title: Mother and Infant Nutrition Investigation (MINI) Study : A cohort of postpartum women
Principal Investigator: Ying Jin
Designation : PHD Candidate Service Area: Womens Health
Research Practice Experience : _____
Other Researchers Involved: Lovise Brough (Massey) Jane Coad (Massey)

Brief description of research study purpose, methodology and reporting:

Purpose:

After the birth of their baby, most women continue to see their health care professionals. However, the focus is often on the infant's health. Only limited attention is given to the mother's mental health. This study will monitor the mothers' health by assessing her nutrient status, thyroid function and mental health. The thyroid is a small butterfly-shaped gland at the base of the neck which produces hormones. How a mother's health status might affect her baby's development during early life is important. The three nutrients we are studying are iodine, selenium, and iron. Understanding these nutrients will help to provide better health care to future mothers. This leads to greater knowledge about the health and wellbeing of both the mothers and their infants.

Methodology:

Advertisements and posters place at selected sites where preganat or post partum women frequently attend. Potential participants will record an expression of interest online or via telephones.Prospective participants will be sent an appropriate study information sheet. Once they indicate their willingness to participate, the researcher will conduct a screening questionnaire to ensure participants are eligible to take part in the study. Informed consent will be obtained. The target number of study participants is 180. Taking

Progress and final reporting:

Section A : Initial Registration and Approval of Research Practice

Documented evidence :

- ☐ Research purpose and parameters
- ☐ Consultation with all MDHB involved parties
- ☐ Risk and indemnity cover
- ☐ Resources required (*eg, staff, equipment, other service involvement)*
- ☐ Approved research budget

Operations Director signature to proceed : Date:

Professional approval

☑ Yes ☐ No ☐ Not applicable

Designation:	Signature:	Date:
ACTING CLINICAL DIRECTOR		14/9/16
CHARGE MIDWIFE	DHNZST	15/9/16

MDHB-7116 Ver.1 2016 This form relates to MDHB-1997 Page 1 of 2

MidCentral District Health Board

MDHB APPROVAL FORM FOR RESEARCH ACTIVITY

External approval *(eg, HDEC, Educational Institution)*

☑ Yes ☐ No ☐ Not applicable

State where from : HDEC

Documented evidence (where applicable):

☐ National application form for ethical review of a research project *(NAF- 2005- v1)*

☐ 'Participants who are unable to give informed consent to participate' form *(NAF- Part 7)*

☑ Locality assessment form

☐ 'Use of human tissue' form *(NAF- Part 5)*

☐ 'Genetic research' form *(NAF - Part 6)*

Section B : Operations Director's Endorsement to Proceed

Proposed start/end dates of research: _____

Operations Director signature _____

Service Line : Women Health Date: 15.9.16.

This submission has been considered to meet ethical and professional requirements, and clearly demonstrate potential clinical, professional and/or strategic benefit to the organisation.

Clinical Board Acknowledgement of Registration

Signed: _____ Designation: CHO/Chair Date: 22/9/16

Copy to be retained by Chief Medical Officer's office and details entered onto Register.

To be completed by the Principal Investigator and Operations Director. The Operations Director is to forward a copy of the form to the MidCentral Health Clinical Board, via Quality & Clinical Risk. All relevant supporting documentation is to be included.

MidCentral District Health Board
Te Pae Hauora o Ruahine o Tararua

Locality Assessment Sign Off for Approval of Research/Clinical Trials

Full project title:	Mother and Infant Nutrition Investigation
Short project title:	MINI

1. Declaration by Principal Investigator

The information supplied in this application is, to the best of my knowledge and belief, accurate. I have considered the potential ethical, resource and cultural issues involved in this research and believe that I have adequately addressed them for this locality.

A formal letter of consultation was sent to the Maori Health Unit on the __/__/__ (date)

Maori Consultation with Dr Maureen Holdaway, Massey University

Name of Principal Investigator (please print):	Ying Jin
Signature of Principal Investigator:	
Date:	25 July 2016

2. Declaration by Clinical Leader of Service/Department in which the Principal Investigator is located

I have read the application, and it is appropriate for this research to be conducted in this department. I give my consent for this locality to be included in the ethics committee application.

Name (please print):	Steven Grant		
Signature:		Institution:	Palmerston North Hospital/MCH
Date:	14/9/16	Designation:	Acting C.D.

- Where the Clinical Leader is also one of the investigators, the Clinical Leader declaration must be signed by the Clinical Executive Director.

MidCentral District Health Board
Te Pae Hauora o Ruahine o Tararua

3. If the application is for a student project, the supervisor should sign the declaration.

I have read the application, and it is appropriate for this research to be conducted under my supervision. I give my consent for this locality to be included in the ethics committee application.

Name (please print):	LOUISE BROUGH		
Signature:	L. Brough	Institution:	~~Palmerston North Hospital/MCH~~ MASSEY UNIVERSITY
Date:	26/7/16	Designation:	SENIOR LECTURER.

4. Declaration by relevant Operations Director

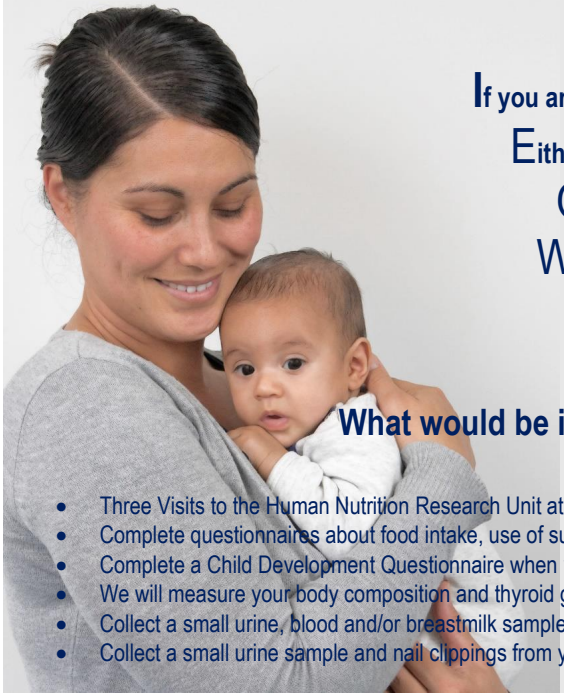
I have read the application, and it is appropriate for this research to be conducted in this department. I give my consent for this locality to be included in the ethics committee application.

Name (please print):	NICHOLAS GLUYAS		
Signature:		Institution:	Palmerston North Hospital/MCH
Date:	23.9.16	Designation:	Ops Director.

Appendix 6: MINI Study Poster

MINI Study –
Mother and Infant Nutrition Investigation

Would you like to find out more about your dietary intake and nutrient status and its effect on both you and your new-born baby?



If you are a healthy woman aged 16 or older
Either in the late stage of pregnancy
Or have recently given birth
We would like to hear from you

What would be involved if joining this study?

- Three Visits to the Human Nutrition Research Unit at Massey University
- Complete questionnaires about food intake, use of supplements, general health
- Complete a Child Development Questionnaire when your baby reaches 4, 8 and 12 months old
- We will measure your body composition and thyroid gland size
- Collect a small urine, blood and/or breastmilk samples and toenail clippings from you
- Collect a small urine sample and nail clippings from your child

We will continue to follow you and your baby's nutritional health until your child is 12 months old

This project has been reviewed and approved by the Health and Disability Ethics Committee: 15NTA172.

Please contact:
Ms Ying Jin (PhD Scholar) through mini@massey.ac.nz
Or Go to www.massey.ac.nz/ministudy

School of Food and Nutrition, Massey University, 027 399 4138/06-951-7556

MASSEY UNIVERSITY
COLLEGE OF HEALTH
TE KURA HAUORA TANGATA

Appendix 7: Participant Information Sheet

Participant Information Sheet

Study title: **[MINI - Mother and Infant Nutrition Investigation]**

Locality: **Palmerston North**

Ethics committee ref: **15/NTA/172**

Lead investigator: **Ying Jin**

Contact **email:** mini@massey.ac.nz
Register your interest –
www.massey.ac.nz/ministudy
Phone: +64 (06) 9517556
027 399 4138

Would you like to help us?

We invite you to take part in a research study: Mother and Infant Nutrition Investigation (MINI). This sheet gives detailed information about the study. Please read it carefully before deciding whether you wish to join our study.

We need mothers and their infants to take part. It is important that you understand why we are doing this research, and what it may involve for you. Please take time to read the sheet carefully. Feel free to discuss it with other people, such as your family, whānau, friends, or your health care providers. Please ask us questions if anything seems unclear, or if you wish to know more details.

Introducing the researchers

This research is led by PhD scholar Ms Ying Jin. Ying's supervisors are Dr Louise Brough and Professor Jane Coad. They are human nutritionists in the School of Food and Nutrition, Massey University, Palmerston North. Anne Broomfield, research officer, will also assist in the study.

What is the purpose of this study?

After the birth of their baby, most women continue to see their health care professionals. However, the focus is often on the infant's health. Only limited attention is given to the mother's mental health. This study will monitor the mothers' health by assessing her nutrient status, thyroid function and mental health. The thyroid is a small butterfly-shaped gland at the base of the neck which produces hormones. How a mother's health status might affect her baby's development during early life is important. The three nutrients we are studying are iodine, selenium, and iron. Understanding these nutrients will help to provide better health care to future mothers. This leads to greater knowledge about the health and wellbeing of both the mothers and their infants.

Do I have to take part?

No. It is entirely up to you to decide whether you wish to take part. If you do agree, you will be asked to sign a Consent Form. You will be given a copy of both the Participant Information Sheet and the Consent Form to keep.

Should you change your mind about being in the study, you are free to withdraw from the study at any time without giving any reason.

What would your participation involve?

If you are interested in taking part in the study, please phone or email us. You can also enter your details on this study's "Express of Interest" webpage. We will reply immediately and arrange a brief telephone conversation. We will ask you some questions to ensure that you are eligible. You must feel totally comfortable about taking part in the study.

Soon after, we shall make an appointment for you and your baby to come into the Human Nutrition Research Unit at Massey University. If this is not possible, we may visit you either at home, at a local community Centre, or at a health professionals' clinic.

During the first visit, we shall

- ask you some questions about your nutrient supplement use, and your nutrition knowledge. We will also ask you about your health, diet and some personal information;
- measure your weight, height, and body composition;
- ask you to provide small samples of urine and breast milk which we will use to assess your nutrient status;
- measure your baby's weight, length and head circumference.
- collect a small urine sample from your baby to assess his/her nutrient status.

Your first visit should take no more than two hours.

After the first visit, you will be given

- two small paper bags for you to collect nail clippings from yourself and from your baby to assess selenium status.
- a 4-day food record diary to measure your nutrient intake.

Within a month after your first visit, at a convenient time, we will collect the samples and food diary from you at home.

The second visit will be when your baby is 6 months old. The last visit will be when your baby is 12 months old. We will ask you to complete a questionnaire to assess your child's development at 4, 8 and 12 months.

A detailed Flow Chart is on pg. 6 of this Information Sheet.

How would the required samples be collected?

A clear detailed instruction of how to collect infant or adult nail clippings would be given at the first visit. Infant urine samples will be collected by placing a pad inside the nappy, checking every 10 minutes until wet, and then urine aspirated (extracted) with a syringe. Blood samples will be drawn by experienced phlebotomist. The collected biological samples will be frozen, labelled with a unique code (no personal information will be displayed on the samples), and then stored for 10 years to allow a number of analyses to take place. After 10 years, the samples will be properly disposed in biohazard bags to be incinerated (burned) by a professional company who specialise in destroying biological samples. We acknowledge that the use and storage of tissue is a cultural concern for some Māori people. We are unable to return body fluids such as blood, urine and breastmilk due to safety (microbiological) issues. However, if you wish, the nail clippings, after analysis, will be returned to you if you request this in advance.

What are the possible risks to you?

There are small risks when taking blood samples such as discomfort, bruising, infection or fainting. To minimise any risk, your blood will only be taken by experienced and fully trained research staff.

Any risks involved in this study are very minor. All of the checks are routinely made. If you have any concerns during the study you may discuss these with any of the study team.

Any complaints you may make will be fully investigated. If you have any concerns about any aspect of this study, you should speak immediately to a member of the study team. They will do their best to answer all of your questions fully.

What are the advantages of taking part in the study?

- Your thyroid gland size, thyroid function and iron status will be monitored during the study. These are not normally covered by primary health care services;
- Repeated screening for postnatal depression during the first year after delivering a baby;
- Based on your food diary, you will receive feedback on your intake of nutrients within a month after we receive the dietary diary. This will be compared to New Zealand standard dietary guidelines.
- You will also receive information about your child's development assessments at 4, 8 and 12 months.

Will my participation in the study be kept confidential?

Yes. All information collected about you and your baby during the study will be kept strictly confidential. Each mother will be given a unique code which will be used on all data collected. No identifying details will be recorded on the interview sheets or other records.

When the study results are presented, you will not be named or recognised from any of the information given. All information will be entered into a protected database at Massey University. Information collected about you and your baby will be kept strictly confidential and secure in a locked filing cabinet. All electronic files on computers will have passwords and restricted access. Only the named members of research team will have access to detailed personal information.

Massey University maintains a central record of all research projects undertaken. This does not include personal information about those who take part. The data (without containing personal information) will be held for 10 years after the youngest person in the study has reached the age of consent or 16 years old.

What will happen to the results?

Should you wish, you will receive all the results about you and your baby. Should your results be, in any way, unusual, you will be encouraged to contact your general practitioner and seek appropriate medical advice. Once the whole study has ended, we can send you a summary of the study results, should you wish to have it. The results will also be presented at scientific meetings or published in peer reviewed journals. This ensures that a wider community, including health professionals, can know and read about the findings. You and your baby will not be identified by any of these publications or presentations.

What would happen if you were injured in the study?

If you were injured in this study, which is unlikely, you would be eligible for compensation from ACC. This would be the same as if you were injured in an accident at work or at home.

If you have private health or life insurance, you may wish to check with your insurer that taking part in this study will not in any way affect your cover.

Who has reviewed the study?

This project has been reviewed and approved by the Northern A Health and Disability Ethics Committee through the full review pathway.

Contact for further information:
If you have any further questions or if you have any concerns whilst taking part in the study then please contact:

Ms Ying Jin, Lead Investigator/PhD Scholar
Email: mini@massey.ac.nz, or go to www.massey.ac.nz/ministudy
Cell phone: 027 399 4138
Telephone: +64 (06) 9517556

Dr. Louise Brough, Principle Supervisor/Senior Lecturer
Telephone: +64 (06) 356 9099 ext. 84575

Email: L.Brough@massey.ac.nz

Where can you go for more information about the study, or to raise concerns or complaints?

If you have any questions, concerns or complaints about the study at any stage, you can contact:

Ms Anne Broomfield, Research Technical Officer
Human Nutrition Research Unit
Massey Institute of Food Science and Technology
Telephone: +64 (06) 356 9099 ext. 84566
Email: A.M.Broomfield@massey.ac.nz

If you want to talk to someone who is not involved with the study, you can contact an independent health and disability advocate on:

Phone: 0800 555 050
Fax: 0800 2 SUPPORT (0800 2787 7678)
Email: advocacy@hdc.org.nz

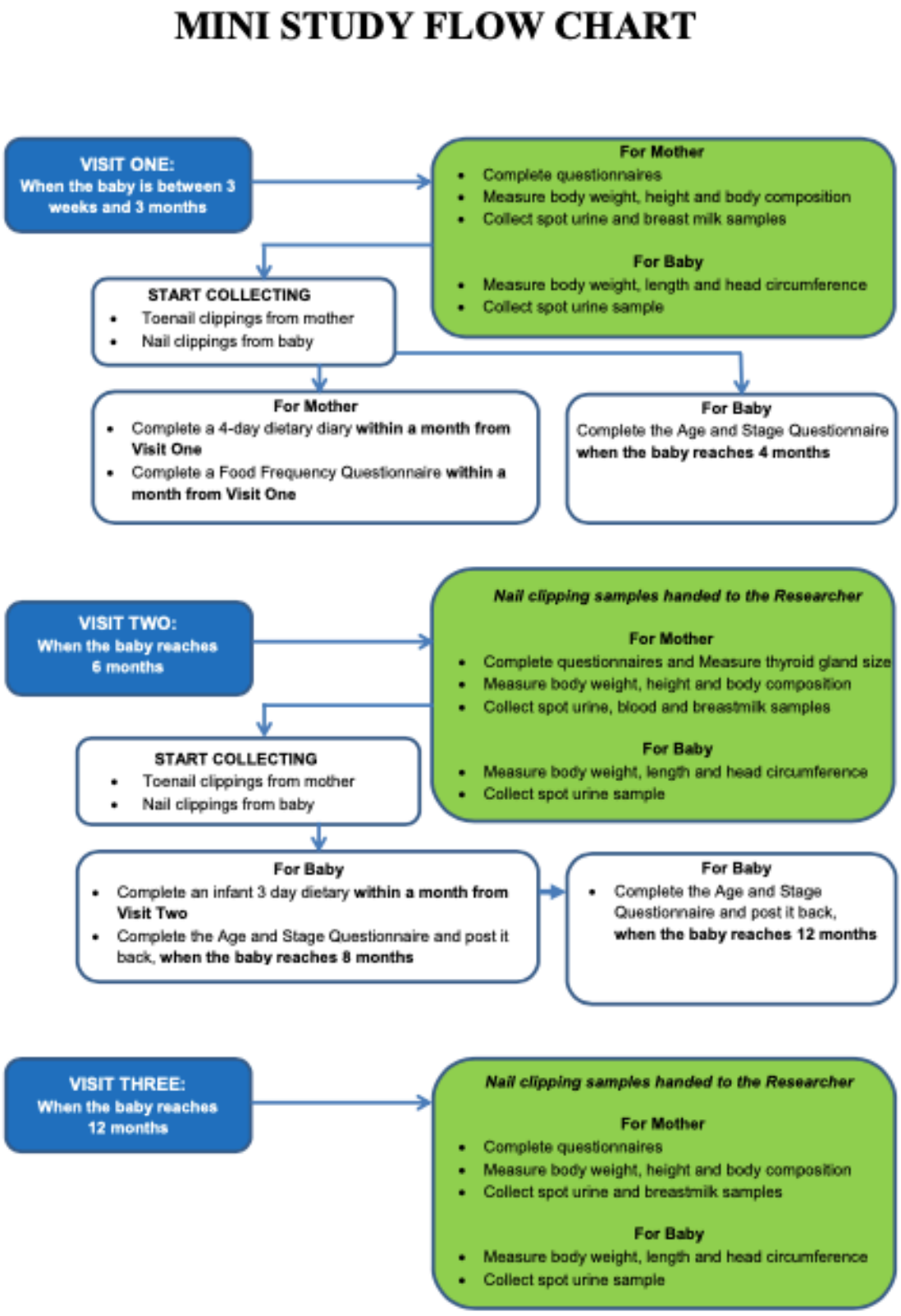
If you feel you would like to talk to a Māori health support person, please contact:

Dr Maureen Holdaway
Associate Director, Research Centre for Maori Health & Development
Telephone: +64 (06) 356 9099 ext. 85092
Email: M.A.Holdaway@massey.ac.nz

You can also contact the health and disability ethics committee (HDEC) that approval this study on:

Phone: 0800 4 ETHICS
Email: hdecs@moh.govt.nz

Appendix 8: MINI Study Flow Chart



Appendix 9: Participant Consent Form

MINI Study - Consent Form

Please tick to indicate you consent to the following

I have been given sufficient time to consider whether or not to participate in this study.		
I have had the opportunity to use a legal representative, whanau/ family support or a friend to help me ask questions and understand the study.		
I am satisfied with the answers I have been given regarding the study and I have a copy of this consent form and information sheet.		
I understand that taking part in this study is voluntary (my choice) and that I may withdraw from the study at any time without this affecting my medical care.		
I consent to the research staff collecting and processing my information, including information about my health.		
If I decide to withdraw from the study, I agree that the information collected about me up to the point when I withdraw may continue to be processed.	Yes ☐	No ☐
I consent to my GP or current provider being informed about my participation in the study and of any significant abnormal results obtained during the study.	Yes ☐	No ☐
I understand that my participation in this study is confidential and that no material, which could identify me personally, will be used in any reports on this study.		
I know who to contact if I have any questions about the study in general.		
I wish the nail clippings to be returned to me after analysis	Yes ☐	No ☐
I wish to receive a summary of the results from the study.	Yes ☐	No ☐

Declaration by participant:

Participant's name: _____

Signature: _____ Date: _____

Declaration by a member of the research team:

I have given a verbal explanation of the research project to the participant, and have answered fully any of the participant's questions concerning this study..

I believe that the participant fully understands the details of this study and has given informed consent to participate.

Researcher's name: _____

Signature: _____ Date: _____

Appendix 10: BIA Results

Table 1

Mean body composition measurements via BIA at 3-, 6-, and 12-months postpartum

	Time postpartum (months)			
	(n=61)			
	Geometric Mean (95% CI)			
Measure	3	6	12	p-value
Total weight (kg)	71.4 (67.7, 75.3)	70.0 (66.2, 74.0)	68.5 (64.7, 72.6)	< 0.001
FM (kg)	23.1 (20.7, 25.7)	21.5 (19.1, 24.3)	19.6 (17.1, 22.4)	< 0.001
BF (%)	33.4 (31.2, 35.5)	32.2 (29.8, 34.5)	30.2 (27.7, 32.7)	< 0.001
FFM (kg)	47.7 (46.0, 49.3)	47.5 (45.8, 49.1)	47.8 (46.1, 49.6)	0.232

ANOVA: repeated measures with time as factor and variable at different time points as measure. P-value taken from greenhouse-geisser.

Table 2

Changes in postpartum body composition components measured via BIA with respect to infant feeding status at 3MPP

Body composition variable measured by BIA	*Measurement point*	*Exclusive Breastfeeding at 3mo (n=53)*	*Mixed Feeding at 3 mo (n=11)*	*Model p-value*		
		Mean (95% CI)	*Mean (95% CI)*	*Time*	*Infant feeding mode*	*Time*Infant feeding mode*
Total FM (kg)	3 months	21.9 (19.6, 24.6)	31.4 (23.4, 42.2)			
	6 months	20.3 (17.9, 23.0)	30.2 (22.0, 41.5)	<0.001	0.011	0.485
	12 months	18.2 (15.8, 20.9)	27.5 (19.3, 39.1)			
Total weight (kg)	3 months	69.9 (66.3, 73.7)	81.5 (68.1, 97.6)			
	6 months	68.3 (64.6, 72.1)	80.3 (67.0, 96.4)	<0.001	0.024	0.621
	12 months	66.6 (62.9, 70.5)	78.5 (65.2, 94.6)			
FFM (kg)	3 months	47.3 (45.6, 49.0)	49.9 (44.0, 55.7)			
	6 months	47.1 (45.4, 48.8)	49.7 (43.6, 55.8)	0.356	0.233	0.526
	12 months	47.4 (45.7, 49.1)	50.3 (44.1, 56.5)			
Body fat %	3 months	32.4 (30.1, 34.7)	39.3 (34.2, 44.4)			
	6 months	31.0 (28.5, 33.4)	38.6 (32.6, 44.6)	<0.001	<0.001	0.780
	12 months	28.8 (26.2, 31.4)	36.3 (29.8, 42.8)			

* Significant difference

Table 3

Changes in mean body composition measures between 3-6 months, 6-12 months, and 3-12 months

	Difference between time points *Geometric mean (95% CI)*		
Measure	3-6months	6-12 months	3-12months
Total weight (kg)	-1.43 (-2.02, -0.85)	-1.48 (-2.35, -0.60)	-2.91 (-4.00, -1.82)
FM (kg)	-1.18 (-1.68, -0.66)	-1.76 (-2.49, -1.02)	-2.93 (-3.84, 2.02)
Body fat (%)	-1.24 (-1.83, -0.65)	-1.97 (-2.67, -1.28)	-3.21 (-4.14, -2.28)
FFM (kg)	-0.26 (-0.57, 0.05)	0.28 (-0.13, 0.69)	0.02 (-0.38, 0.42)